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FINAL REPORT

Cooperative Agreement 28-CCS7-029

ASSESSMENT OF THE ECONOMIC BENEFITS OF LIVING SNOWFENCES

Prepared for:
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CHAPTER 1 INTRODUCTION

Living snowfences are tree or tree and shrub plantings designed to control blowing and drifting snow. Rows of trees and shrubs are planted so that they form a barrier to the wind collecting blowing snow in drifts. These living snowfences normally have a useful life of 50 years. Species selection for plantings is determined by management objectives and site conditions. Fast-growing, long- lived species have the potential for the greatest economic returns. Living snowfences are used in many areas and serve as protection for roads, agricultural fields, livestock and homesteads.

Preventing blowing snow from drifting on roads reduces snow and ice removal costs, and therefore maintenance costs of snow removal machinery and roads. Improved visibility and road conditions leeward of snowfences result in reduced accident frequency and travel delays during times when blowing snow would be a problem. Trapping blowing snow and distributing it across agricultural fields increases soil moisture in spring when the snow melts and, by reducing wind-speeds leeward of the snowfence, reduces wind-caused soil erosion.

Living snowfences also act as 'living barns' for livestock by providing protection from wind and blowing snow in the winter. This protection reduces stress to livestock which translates into less energy expended to keep them warm. This in turn results in lower feed costs and higher market value for the livestock. Finally, living snowfences protect homes from blowing and drifting snow. This results in reduced heating bills and less time and energy expended on keeping access open.

While the types of benefits incurred by living snowfences are well known, their economic impact is less clearly understood. This paper develops an economic analysis procedure to analyze the benefits and costs associated with snowfences designed to protect roads. This analysis procedure is to evaluate the economic performance of living snowfences as well as artificial snowfence alternatives.

The paper is organized in the following manner. First, the literature review presents information pertaining to the design, maintenance, costs and benefits of all types of living snowfences. The review concentrates on providing an understanding of what is involved in designing and maintaining a living snowfence system as well as what kinds of benefits can be expected from it. Second, is a description of the economic analysis procedures that will be used in evaluating the snowfences. This chapter includes a description of the analysis criteria, how they are calculated and how they can be interpreted. The next chapter provides a detailed economic analysis of four snowfence case studies or scenarios. The scenarios use data from a study by Ron Tabler (1982) which was conducted along a section of I-80 in Wyoming. The study utilized artificial snowfences and quantified the benefits of this snowfence system in terms of savings in snow removal costs and reduction in vehicle accidents. The economic analysis provides of calculations of several economic performance criteria, cost distributions and a sensitivity analysis. The analysis concludes with a discussion of how each scenario's design performs individually as well as in comparison to the other scenarios. Finally, the last chapter discusses the basic conclusions and recommendations of the research.

CHAPTER 2 LITERATURE REVIEW

2.1 Introduction

Manipulation of wind direction and snow distribution through the use of living snowfences[1] (LSF's) is an effective way to combat some of the problems created by blowing and drifting snow in the Great Plains region. Manipulation of drifting patterns near roads help to keep the roads clear, improve transportation safety and reduce snow removal costs (WACD, 1990). Living snowfences can double as field windbreaks to prevent soil erosion and increase soil moisture on agricultural lands. Livestock operations can also benefit from the protection of a living snowfence through lower winter mortality rates, improved animal health and lower feed costs. Homes and other structures can be protected from high winds and drifting snow through the use of living snowfences. In sum, there are numerous uses and benefits of living snowfences.

2.2 Design Standards

Design specifications of living snowfences vary depending on the objectives that it is intended to achieve, location and site characteristics, and available resources. The following discusses design specifications for living snowfences for specific wind and snow control objectives.

[1]For the purpose of this project, living snowfences will be defined as any tree or tree-shrub combination designed to capture or divert blowing and drifting snow. This definition includes field windbreaks in areas where they have an effect on snow distribution.

2.2.1 Roads

There are a number of recommended design specifications for all snowfences, living or artificial, designed to control drifting on roads. For example, the orientation of the snowfence to the road is important. The snowfence must be aligned so that it intercepts blowing snow before it gets to the area requiring protection. The ideal orientation is perpendicular to the prevailing wind. The standard LSF orientation, in the Great Plains, is north of east-west roads and west of north-south roads (Brandle and Nickerson, 1996). To ensure that the leeward edge of the snow is stored by the snowfence, the snowfence should be no closer than 150 feet and no further than 300 feet from the centerline of the road (Shaw, 1987; Brandle and Nickerson, 1996; Perko, 1994; WACD, 1990). However, Shaw (1987) indicates that the wider the barrier and the more dense it becomes the closer to the road it can be. Because of eddying effects at the ends of the snowfence and the decreased snow storage capacity in these areas, it is also suggested that each end of the fence extend at least 100 feet beyond the area being protected (Perko, 1994; WACD, 1990). In areas where drifting occurs at the steep leeward slopes of road cuts, the snowfence should be positioned approximately 100 feet to the windward side of the crest and parallel to the ridge line (Brandle and Nickerson, 1996). Planting near road intersections should be avoided to prevent the snowfence from creating visibility problems (Brandle and Nickerson, 1996).

The species to be planted depends on site conditions and available space (Brandle and Nickerson 1996; Shaw, 1987). In general, one rule of thumb is the taller the snowfence, the better (Perko 1994; WACD, 1990). For more effective wind control and added snow storage, it is recommended that a minimum of three rows of trees be planted, or a combination of trees and shrubs, with at least two rows being conifers (Brandle and Nickerson, 1996). Single- or twin-

row plantings (LSF's with less rows should typically have higher density) may be appropriate where space is limited and annual precipitation is not so great that the snowfence cannot be effective (WACD, 1990). Once the snowfence is established, a density of 50-60% will maximize the snow storage capacity (Brandle and Nickerson, 1996; Perko, 1994; Shaw, 1986). Density refers to the percent of the frontal area that leaves, branches, twigs, and trunks occupy (WACD, 1991). Spacing between rows should be between 40 and 75 feet to maximize their individual and collective effectiveness on wind reduction and snow storage capabilities (Shaw 1987; WACD,1990). Spacing between trees ranges from 6 feet to 12 feet depending upon species (WACD, 1990).

For each row it is recommended to till a strip 8 feet wide, and up to 12 inches deep the fall before planting in order to remove any competing vegetation (Shaw, 1987; WACD, 1990). Planting should be done in the spring. In areas where weeds are a major problem, herbicides should be applied the spring before planting. Once seedlings are planted, some additional form of weed control is needed . Mulching, laying plastic weed barriers, fertilizer tablets, and herbicides can be used to prevent weed competition and facilitate establishment. Seedling mortality should be replaced immediately with new seedlings. Fencing should be placed around all living snowfences in order to keep out livestock and wildlife that may cause damage to the seedlings (Boehner et al., 1991).

In areas where precipitation is less than 22 inches per year, some form of irrigation is normally necessary (UMN,1996). The irrigation system is necessary to fulfill the moisture needs for the first five years after planting (WACD, 1991). Where mulch is used irrigation systems may not be needed because the mulch will retain adequate moisture (Shaw, 1987).

2.2.2 Field

Living snowfences can be used in fields to protect agricultural crops and grazing lands. These barriers to wind and snow help protect the fields year-round. The purpose of these snowfence/windbreaks from a snow management standpoint is to increase soil moisture, reduce soil erosion and the need for emergency tillage, and store water in stock ponds (Emergency tillage is a high cost practice that roughens the land surface, thus reducing wind velocity and capturing drifting soils). One important consideration in designing field windbreaks is to achieve the desired effect while minimizing the space required for the windbreak. Depending upon the purpose of the barrier, it can be used to distribute snow evenly across a large area or confine snow to a small space (Brandle and Nickerson, 1996; WACD, 1991).

Snowfences designed to evenly distribute snow across the land can provide additional moisture and increase productivity of crop fields and range land. In this case, the trees of the snowfence should be widely spaced (15-20 feet between trees), and have a density no greater than 40%. As with road snowfences, field windbreaks become more effective with increasing tree height (Brandle and Nickerson, 1996; WACD, 1991).

Confining the snow to a small area requires a design similar to snowfences used to protect roads. Multiple, dense rows of trees will allow for snow to be captured in stock ponds on the windward side increasing their effectiveness. The design reduces the ability of high winds to erode soils, virtually eliminating the need for emergency tillage (WACD, 1991).

2.2.3 Livestock

Living snowfences can be an effective tool in protecting livestock. In this case, the design is similar to that used to protect roads. The purpose of the windbreak is to control snow to allow access by ranchers to the livestock and the livestock to feed bunks. Further, by reducing the winter winds the livestock will maintain a higher body temperature, thus decreasing the amount of feed they need to maintain body weight and temperature. Multiple rows of trees and shrubs, with at least one being a dense conifer, will produce the desired effect. Spacing between deciduous trees should be 6 to 15 feet, 6 to 20 feet for conifers, and 3 to 6 feet for shrubs. If space is limited, twin row, high density windbreaks can also be used. The windbreak should be 75 to 100 feet windward of the area to be protected. A fence is required around the snowfence and should extend 75 to 100 feet leeward of the windbreak to prevent livestock from entering the windbreak area. A wrap-around design in the shape of a 'C' or 'L' helps provide protection from prevailing winds coming from multiple directions (Quam et al., 1994; WACD, 1990).

2.2.4 Home

Design of snowfences to protect homes is similar to those for protecting livestock. They create a buffer from high winds and windchill, trap snow and reduce energy costs. For best results, the snowfence should be located as close to the home as possible without allowing snow to drift on the structure. This design will provide the greatest protection from high winds (WACD, undated; Wight et al., 1991). Keeping drifting snow off of driveways is crucial to maintaining access to home sites. In this case, the design should be similar to that for roads, discussed earlier.

2.3 Living vs. Artificial Snowfences

Another well-known alternative being used to control blowing and drifting snow is the artificial snowfence. Artificial snowfences range from 4 to 14 feet in height (WACD, 1990). Their orientation to the area being protected and length follow the same guidelines as living snowfences. There are many types of artificial snowfences, with the Wyoming snowfence being the most popular and effective. The Wyoming snowfence is constructed with either wood or metal posts anchored with rebar. Wooden boards are then laid out across the posts creating a fence or barrier. The average density, or porosity (holes or spaces in the fencing material expressed as a percentage of total frontal area of the fence), of this type of fence is 45% (Tabler, 1991).

There are advantages and disadvantages to both the artificial snowfence and the living snowfence. One major advantage of the living snowfence is that it typically will attain a greater height and depth than any of the artificial snowfences. This greater height and depth translates into more snow storage capacity and greater leeward wind blocking capabilities (WACD, 1990). Another major advantage is the life span of living snowfences. It is estimated that a living snowfence will have a life span of 50 years before it needs replacing, whereas the useful life of an artificial snowfence, such as the Wyoming snowfence, is estimated at 20 years (Perko, 1997; Shaw, 1997) The living snowfence provides additional secondary benefits compared to artificial barriers. These include wildlife habitat and aesthetic values. The artificial snowfence also normally has higher annual lifetime costs (Shaw, 1986; 1987; 1997).

On the other hand, there are advantages to using artificial snowfences. Artificial barriers can be set up almost anywhere but living snowfences are limited to those sites where conditions

suit tree/shrub establishment. Living snowfences also take time to reach an effective height whereas artificial barriers produce results immediately after installation. Living snowfences are also susceptible to insect and disease damage. Finally, initial maintenance and establishment costs (e.g. irrigation) may not make the living snowfence the least expensive or feasible option in some areas (Tabler, 1991).

2.4 Costs

Living snowfences have a relatively high initial investment for the site preparation, planting, and initial maintenance (Shaw, 1997). However, after the snowfence is established, the cost of maintaining the snowfence is minimal. When considering the average yearly costs throughout the life of the snowfence the costs are quite low. Most cost comparisons between living and artificial snowfences indicate that living snowfences cost less to establish and maintain (Shaw, 1997; Perko, 1997).

The Colorado Interagency Living Snowfence Program reports living snowfence establishment costs ranging from less than $15,000 per mile, to just more than $20,400 per mile (the lower cost is interagency installation the higher is contractor cost), for a three row tree and shrub LSF design. This cost includes all labor and materials for establishing the snowfence including protective fencing, fabric mulch and fertilizer tablets (Shaw, 1997). In comparison, data for the installation of a 13.8 foot high Wyoming design board fence indicates an installation cost of $87,067 per mile (Shaw, 1997). This cost includes all labor and materials for installation. As can be seen the living snowfence is clearly much cheaper, even if installed by private contractor.

Maintenance costs for living snowfences are also less than those for the Wyoming board fence. The Colorado Living Snowfence program estimate maintenance costs at $3000 per mile for plantings the first three years, and $469 per year over the lifetime of the living snowfence. Maintenance costs for the Wyoming board fence are $5,280 per year over the lifetime of the fence (estimated to be 20 years) (Shaw, 1997).

When both establishment and maintenance costs are combined and spread out over the life of the snowfence, the living snowfence is estimated to cost $469 per mile per year (over 50 years)(Shaw, 1997). Similar cost estimates were derived for living snowfences in Wyoming - $612 per mile per year (Perko, 1997). The Wyoming board fence is estimated to cost $6993 per mile per year (over 20 years) (Shaw, 1997). Other agencies report similar costs for both living and artificial snowfences in their regions (SDDOA, 1997).

2.5 Benefits

Living snowfences established to prevent blowing and drifting snow on roads create a variety of benefits for both public and private interests. Transportation departments benefit from the reduction in snow accumulation on the road that translates into lower snow removal costs and less wear and tear on snow removal equipment (WACD, 1990). The traveling public benefits because roads are safer, visibility is improved, delays are less likely, and roads are less probable to have closures (Tabler, 1991). Money saved in snow removal costs may also be translated into less taxes having to be paid by the public.

Any snowfence located on agricultural land will create benefits of increased soil moisture where snow is deposited. This results in greater crop production and improved grazing

conditions. Soil and water erosion are reduced on the leeward side reducing the need for emergency tillage (WACD, 1991). Living snowfences designed to protect livestock, benefit the rancher as a result of lesser stress on the animals resulting in lower winter mortality, lower feed costs, and the ability for livestock to maintain body weight thus giving them a higher market value (Quam et al., 1994). Snowfences used to protect homes result in lower energy costs, less wind damage to exterior siding, decreased wind effects in both summer and winter, and aid in keeping access to driveways open (WACD, undated) . The establishment of a living snowfence provides almost immediate habitat for wildlife and an aesthetically pleasing appearance (Shaw, 1986).

CHAPTER 3 ASSESSMENT OF BENEFITS

3.1 Introduction

Assigning economic values to the various public and private benefits derived from living snowfences will, in some cases, require drawing parallels to benefits incurred from artificial snowfences. Comparisons are necessary as there is little data available quantifying specific benefits for just living snowfences.

3.2 Snow and Ice Removal

Assessing the reduction in road snow and ice removal costs as a result of living snowfences can be made using a study done by Tabler and Furnish in 1982 entitled, Benefits and costs of artificial snowfences on Wyoming Interstate 80. In this study artificial snowfences were installed in a 45.5 mile section of Interstate 80 in Wyoming. Changes in snow removal expenditures were examined along the study section and the rest of I-80 (approximately 341.76 miles). Cost per mile estimates can be calculated and analyzed to see if the increase in snowfence protection has any effect on snow and ice removal expenditures (See Table 3.1). The average cost per mile in the study site from 1972 through the winter of 1981 is $2231.68 (adjusted to reflect 1971 dollars). This is significantly less than the $5182.42 per mile calculated for 1971 (The expenditures for 1971 are used for comparison because only 4.54% of the study area is protected by snowfences and is the closest to what the cost per mile estimate would be for 0% protection). This reduction in cost per mile over the 10 year span of the study can be attributed to the implementation of the artificial snowfences. The mean precipitation over the ten year span (1972-winter 1981) is 30.93 which is approximately equal to that recorded for 1971

(see table 3.3). This eliminates the effect precipitation may have on the comparison.

Table 3.1 Expenditures for snow and ice removal, miles 235-280.5, Wyoming I-80. (See Tabler 1982, pg 17)

Period	Snow-Fence Protection (%) miles 235-280.5	Expenditure ($)		Cost/mile ($) Mile 235-280.5	Cost/mile remainder of I-80
		Mile 235-280.5 with snowfences	Remainder of I-80 without snowfences		
Jan. 1-Dec. 30, 1970	0	-	-	-	
Jan. 1-Dec. 30, 1971	4.54	235,800	489,485	5182.42	1432.25
Jan. 1-Dec. 30, 1972	12.82	104,147	393,177	2288.95	1150.45
Jan. 1-Dec. 30, 1973	16.55	137,055	360,613	3012.20	1055.16
1973-1974 winter	32.34	175,442	604,979	3855.87	1770.19
1974-1975 winter (to Feb. 1)	36.71	53,710	219,634	1180.44	642.66
1975-1976 winter	40.20	No data	No data	No data	No data
1976-1977 winter	40.20	118,729	294,597	2609.43	862.00
1977-1978 winter	44.04	227,184	623,397	4993.06	1824.08
1978-1979 winter	53.17	297,777	856,804	6566.53	2507.03
1979-1980 winter	53.17	345,580	1,141,134	7595.17	3338.99
1980-1981 winter	53.17	137,240	574,315	3016.26	1680.46

3.3 Accidents

Another important result of the Wyoming study is the impact that snowfences have on the frequency of winter road accidents and the benefits of improved visibility (see Table 3.2). The study suggests that as snowfence protection(% of section) increased, the number of ground blizzard accidents decreased. In the winter of 1970-1971, the study section had no protection from snowfences and there were 55 ground blizzard accidents. Compare this to the 1979-1980 winter, in which 50.95% of the study section was protected by snowfences, and there were only 33 ground blizzard accidents. This study also suggests that there is a decrease in the number of accidents caused by wind. For example, from the winters of 1970- 1971 to 1973-1974 the were an average of 43.25 wind-related accidents and less than 30% snowfence protection, compared to the winters of 1974-1975 to 1980-1981 where there were only an average of 27 wind-related accidents. These conclusions are further justified considering the fact that there were 235,000 more total vehicles in 1980-1981(920,676 total vehicles) than in 1970-1971 (683,020 total vehicles). Using this accident frequency data along with estimates of damage costs per accident a valuation of economic benefits due to reduction in accidents can be made. It is important to note that these are estimates of damage costs per accident in that year. Therefore, the figures are not in constant dollars or adjusted for inflation.

Table 3.2 Road closure and accident data, October 1 to April 30, 1970-1981, Wyoming I-80, Miles 235-295. (See Tabler, 1982 pg. 18)

Winter	Snow-Fence Protection (%) miles 235-295	Total Vehicles per year	Winter Precipitation (cm)	Time Closed (Days)	Accidents*					
					Total	Snow	Ground Blizzard	W ind	Other	Valuation /accident ($)
1970-1971	0	683,020	32.3 (+-3.6)	8.4	148 (110)	32(18)	55(48)	27 (20)	34 (24)	1301
1971-1972	7.54	662,655	28.4	6.2	128(57)	12(4)	41(27)	54 (21)	21 (5)	1683
1972-1973	13.20	527,043	45.9	14.8	187(101)	28(18)	62(36)	40 (19)	57 (28)	1180
1973-1974	28.21	554,560	32.8	7.8	132(70)	17(9)	36(25)	52 (24)	27 (12)	1639
1974-1975	31.52	666,669	28.4	5.3	94(52)	20(25)	25(3)	28 (12)	21 (12)	1763
1975-1976	34.17	708,192	30.6	4.4	140(66)	20(10)	52(28)	38 (12)	30 (16)	1236
1976-1977	34.17	818,456	22.6	1.5	84(59)	20(20)	13(11)	7 (7)	44 (21)	1711
1977-1978	37.08	857,638	25.4	4.8	133(82)	23(10)	27(14)	36 (22)	47 (36)	1846
1978-1979	44.00	941,716	35.0	9.4	145(85)	24(10)	49(32)	30 (19)	42 (24)	2930
1979-1980	50.95	779,443	41.4	15.6	163(88)	33(16)	29(26)	43 (15)	58 (31)	2994
1980-1981	50.95	920,676	18.8	0.7	61(53)	20(16)	2(4)	7 (5)	32 (28)	3041

*injuries plus fatalities are shown in parenthesis

3.4 Road Closures

Another important conclusion that can be drawn from the Wyoming study is that snowfence protection will not prevent road closures. The study suggests that road closure due to adverse weather conditions is more of a subjective decision based on visibility along the entire

section of road. Any areas not protected by snowfences may experience poor visibility and require the entire road to be closed. This seems to suggest that only when road is 100% protected from blowing and drifting snow and poor visibility conditions will there be a significant reduction in road closures.

3.5 Field

There have been many studies done regarding the private sector benefits of field windbreaks on the enhanced production of agricultural crops. Many of these benefits can be attributed to the change in the microclimate leeward of the windbreaks and most of these benefits occur during the growing season through improving water use efficiency and decreasing evaporation rates (Kort, 1988). These same field windbreaks can also act as living snowfences in the winter and serve to prevent soil erosion during the winter and provide added moisture when accumulated snow melts in the spring.

Researchers have found that single row windbreaks can increase crop production. These increases are in the range of about 15% for corn, 18% for rye, and 12% for winter wheat (Kort, 1988).

3.6 Livestock

Livestock benefits from windbreaks have also been quantified. A 2% increase in calving success has been found by Kansas cattle producers where cows are protected by windbreaks. Other studies show that cattle on open winter range need 50% more feed to maintain everyday activity along with another 20% to compensate for exposure to wind and snow(Quam et. al.,

1994). The protection of a field windbreak can reduce these extra feed needs by one-half. Additional studies show that beef cattle gain 35 more pounds in protected areas during mild winters and maintained 10 pounds more in severe winters compared to beef cattle located in unprotected areas (Quam et al., 1994).

3.7 Home

The private sector benefits of living snowfences in protecting homes have also been quantified. A case study published in 1993 by John Fusaro titled, "Windbreaks Save Energy and Water," shows that home heating costs can be reduced by about 40% with the use of a properly installed snowfence. The data shows how the amount of gas used to heat the house declined over a 20-year span as the snowfence grew and became more effective in modifying the microclimate around the house(Fusaro, 1993)(see Table 3.3). It is important to note that a portion of the reduction in the use of natural gas may also be due to an increase in the relative price of natural gas.

Table 3.3 Heating gas expenditures for Marv Strachan property from 1973-1992 (Fusaro, 1993)

YEAR	GAS USED (HUNDRED FT^3)	HEATING DEGREE DAYS (6301/YR FT COLLINS AVG.)***	GAS USED/DEGREE DAYS
1973	2238	6484 COLD YEAR	.3451
1974	2080	6064 WARM YEAR	.3430
1975	2178	6470 COLD YEAR	.3366
1976	1940	6127 WARM YEAR	.3166
1977	1946	5657 WARM YEAR	.3439
1978	2090	6618 COLD YEAR	.3158
1979	2094	6605 COLD YEAR	.3170

1980	1968	6264 WARM YEAR	.3141
1981	1682	5452 WARM YEAR	.3085
1982	2116	6441 COLD YEAR	.3285
1983	1993	6627 COLD YEAR	.3007
1984	1929	6470 COLD YEAR	.2981
1985	1607	6702 COLD YEAR	.2397
1986	1271	5599 WARM YEAR	.2270
1987	1180	5934 WARM YEAR	.1989
1988	1239	6140 WARM YEAR	.2018
1989	1317	6195 WARM YEAR	.2126
1990	1290	6043 WARM YEAR	.2135
1991	1490	5916 WARM YEAR	.2519
1992	1353	5754 WARM YEAR	.2351

***Heating degree day = 65°F - average daily temperature (if average daily temperature is below 65°F)
Heating degree days for 1 year is the sum total heating degree days for the year

Living snowfences also provide wildlife habitat and aesthetic beauty. Both of these benefits are difficult to quantify for any situation. However, the contingent valuation and the travel cost methods are two possible methods for deriving economic benefits (Bergstrom, 1989). As with the other benefits discussed, wildlife and aesthetic benefits would change over time as the living snowfence vegetation matures.

CHAPTER 4 ECONOMIC ANALYSIS

4.1 Introduction

Analyzing the benefits and costs of a living snowfence project provides a foundation for comparison of the project to other alternatives such as artificial snowfences and other living snowfence designs. The three main components of this analysis are the net benefits, the internal rate of return, and the benefit-cost ratio[2].

4.2 Net Benefits

Net benefits are the difference between the benefits and costs of a project, calculated by discounting the benefits and costs out to the expected lifetime of the project. There are two ways of analyzing the net benefits; the first is calculating the Soil Expectation Value(SEV) and the second method is the Present Net Value(PNV). The SEV method looks at the project as a perpetual series (ie., occurring at 50 year periods forever). PNV assumes the project occurs over a set period of time (ie., one 50 year project) The net benefits can vary depending on the lifetime of a project and the interest rate on investment.

4.3 Internal Rate of Return

The Internal Rate of Return (IRR) is the interest rate where the discounted costs and

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[2]The information for the economic analysis is taken from Davis and Johnson. "Forest Management." 3rd Edition 1987.

It should be noted that an economic analysis can include cost effectiveness as an evaluation criterion . Since this analysis is concentrating on benefits, cost effectiveness has not been included in the evaluation

benefits are equal. The IRR is used to evaluate projects when an appropriate interest rate can't be identified to analyze net benefits. The IRR can be determined using the SEV or PNV formulas. Analyzing the IRR using the SEV gives the rate of return assuming the project is repeated to infinity. Using PNV to calculate the IRR gives the rate of return for one rotation of the project. Thus in the case of the PNV, the IRR will differ with varying expected project lifetimes. For example, two projects may give the same net benefits, but if one of the projects achieves those net benefits in 10 years as opposed to 20 years for the other, then it is obvious that the project that only took ten years will have a higher IRR and may be the better choice. This demonstrates one weakness of the IRR because it does not consider length of time for the investment.

4.4 Benefit-Cost Ratio

The benefit cost ratio is found by dividing the discounted benefits by the discounted costs. What is important is that the benefits and costs are compared at the same period in time. The benefit-cost ratio gives an indication of the returns per dollar spent. The benefit-cost ratio is an important tool because it can be used to decide between two projects with the same present net benefits. The benefit-cost ratio determines how efficiently money is being spent.

From this discussion it can be seen that no one component of the analysis can provide enough information to decide between two alternatives. The net benefits determine if there is something to be gained from the project. The IRR determines if there are gains (or losses) and how they compare to those of another project. And the benefit cost ratio will determine how efficiently money is spent. However, it is important to note that these components may not be based on the same time frame from project to project. The SEV is the only component of the

analysis that puts all alternatives on the same time frame (infinity). The criteria give the same ranking of alternatives when they are based on the same time frame.

4.5 Rate of Return

Another important factor in the economic analysis is the rate of return used when compounding and discounting. The group responsible for funding a project should use the rate of their best alternative investment. For example, if the best alternative to a living snowfence project is investment of the money into a mutual fund that has a rate of return of 15%, then 15% should be used as the interest rate when analyzing the benefits and costs of the living snowfence project. However, this assumes that the risk of investing in the snowfence project is the same as investing in the mutual fund. If the risk of investing in the snowfence project is lower then the interest rate used in analyzing the project may be lower. Typically less return is acceptable with less risk. The opposite is true if the risk of the snowfence project is higher than the risk of the alternative investment. The interest rate chosen should also reflect the inflation rate. If the annual inflation rate is expected to be 3% during the course of the project then the interest rate chosen should include this estimate to cover the costs of inflation.

4.6 Sensitivity Analysis

All of these analysis techniques are sensitive to the costs, benefits, rate of return and expected lifetime of the project. Changing these values can lead to one alternative becoming less desirable and another more so. To account for this a sensitivity analysis will show these changes and may provide more options as to what course of action can be taken.

Knowing the minimum amount of benefits needed from a project may be important. Calculating the breakeven benefit for a project may also be helpful in doing an economic analysis. If having a net benefit is not an issue in determining what project will be chosen or benefit values are not accurate or available then calculating what benefits are required to cover the costs of the project may be the deciding factor. For example, if two alternatives achieve the same goal and one covers the cost of investing in the project and the other does not then it is clear which is the better option.

4.7 Land Rent

Land rent is one final consideration that needs addressing before an economic analysis can be made for living snowfence projects. If a living snowfence is to be placed on right-of-way land then land costs are of no concern unless there is some opportunity cost associated with this (land could be leased to private farmer for agriculture). However, if the land is privately owned and the funding agency needs to compensate the landowner for the use of the land then this is an additional cost that must be included in the analysis.

4.8 Formulas

The following illustrate typical formulas used to analyze costs in a LSF application.

Compounding Procedures

Value of establishment costs at year 50 = $V_{50} = V_0(1 + i)^t$

V_0 = establishment costs = \$15,000-\$20,400/mile
i = interest rate
t = 50 years

Value of maintenance costs at year 50 = $V_{50} = V_0(1 + i)^t$

V_0 = maintenance costs = \$1,000/mile
i = interest rate
t = 50, 49, and 48 years (maintenance costs are incurred over the first 3 years of the life of the snowfence)

Value of land rent at year 50 = $V_{50} = V_0(1 + i)^t$

V_0 = land rent = $x/mile
i = interest rate
t = 50 years

Calculating the benefits of a living snowfence project are more complicated because the benefits incurred are a function of the development of the snowfence and therefore change with time. The following calculations apply to when the snowfence has reached full effectiveness which is a function of site, climate and species used.

*Value of snow and ice removal savings at year 50 = $V_{50} = a[((1 + i)^n - 1)/i]$

a = savings in snow and ice removal costs for year
i = interest rate
n = number of years savings are experienced

* This equation can be used for all benefits of living snowfences (accident savings, agriculture and livestock benefits, etc.)

The same calculations can be made for the benefits before the living snowfence has reached full effectiveness, but are calculated as a percentage of their full value and compounded from the time they are incurred.

Discounted net benefits = discounted total revenues (benefits) - discounted total costs

Or $PNV = a/(1+i)^n$

a = net returns
i = interest rate

With this information we can calculate the internal rate of return

$SEV=0 = a[1/((1 + i)^t - 1)]$

a = net return
t = 50 years
i = internal rate of return

Benefit-cost ratio

(Discounted benefits)/(Discounted costs)

Annual Breakeven benefits = (Compounded costs)/(length of the project)

The sensitivity analysis would follow the same procedures of compounding benefits and costs but the returns, costs, rate of return and expected lifetime of the project could differ.

CHAPTER 5 CASE STUDIES

5.1 Introduction

The benefit and cost data to be used in the case studies is that summarized in a study done by Tabler (1982). In this study he evaluated the effects of an artificial snowfence system established along a study section of I-80. This data will be used for an economic analysis of four different snowfence case studies or scenarios. The first scenario will consist of implementation of a 13.8 foot Wyoming-type board fence, the second a three row tree/shrub living snowfence, third a four foot slatted snowfence and the last scenario will involve a combination of the three row tree/shrub living snowfence and a four foot slatted snowfence. The Wyoming board fence scenario will be evaluated using a 20 year project life, 50 years for the living snowfence, 8 years for the slatted snowfence and 50 years for the combination slatted and living snowfence.

The benefits incurred as a result of the snowfence system used in the study, and all cost data of establishment and maintenance from each scenario, will be converted to 1998 dollars. Each snowfence scenario will follow the design guidelines as those used in the I-80 study to ensure that the benefits achieved from each scenario will be similar. Using the same design guidelines means that the key differences between each of the scenarios will be the establishment and maintenance costs as well as the useful life of each design. An important note to make in the case of the living snowfence design is that benefits will be evaluated from the time it reaches full effectiveness because no reasonable estimates can be made about the percent of full benefits achieved while the living snowfence is developing. A designated time will be set to determine when full benefits will incur and this time will be varied to provide insight into how the design

might perform in areas with different growth rates. It is also important to note that the artificial snowfence in the other scenarios will take only one year to construct and be effective. An interest rate of 5% will be used in dealing with the benefits and costs in the analysis (Bratton, 1998). An inflation rate, also 5%, will be used to adjust the benefit and data to 1998 dollars. This rate was determined using the producer price index for all commodities to determine the average rate of inflation over the years from 1972 to 1998. Most of Tabler's (1982) data is from 1972. Cost data for 1997 will be used in the analysis for the Wyoming Board Fence and the Living Snowfence scenarios because they are recent and do not require adjustment.

Reduction in snow and ice removal costs, ground blizzard accident frequency and wind-caused accident frequency will be the three basic benefit categories used in evaluating the benefits incurred from the snowfences. It is important to note that there are other benefits that exist as a result of developing a snowfence system such as decreased traveling delays, agriculture- related benefits and in the case of living snowfences there are wildlife and aesthetic components. These additional benefits not directly included in the analysis will be discussed in greater detail at the end of the analysis.

5.2 Benefit and Cost Data

Each snowfence scenario uses data from 32.93 miles of fence protecting 30.45 miles of I-80. All costs and benefits will be expressed on a per mile of snowfence basis so that they can be applied to other snowfence scenarios. The analysis assumes that there is a positive linear relationship between the number of miles of snowfence installed and the benefits incurred. It is also assumed that the benefit data applies to both artificial and living snowfences. The

analysis will provide values on a per mile basis so that they can be applied to areas with similar weather conditions and traffic volume.

5.2.1 Snow and Ice Removal Cost Savings

As discussed previously, the implementation of the artificial snowfence system in Tabler's (1982) study, resulted in a reduction in snow and ice removal costs from $5182.42/mile down to $2231.68/mile (adjusted to 1971 dollars), or a net savings of $2950.74/mile/year. This value is based on 45.5 miles in the study section. Assuming all of the savings is due to the effects of the snowfence, and adjusting this value to reflect a per mile savings based on the 32.93 miles of snowfence established, results in an annual snow and ice removal cost savings value of $4077.09/mile/year of snowfence (1971 dollars).

5.2.2 Vehicle Accident Reductions

As previously discussed, the snowfence in Tabler's (1982) study resulted in a reduction of 22 ground blizzard accidents per year and 17 wind-related accidents per year. The economic value of this reduction in accident frequency will be based on the 1981 estimate of $3041 per accident (Tabler 1982). These values translate to $2031.64 per mile of snowfence per year for ground blizzard ($3041 per accident * 22accidents per year / 32.93 miles of snowfence]) and $1569.91 per mile per year of snowfence for wind-related accidents ($3041 per accident * 17 accidents per year / 32.93 miles of snowfence)(1981 dollars). The value for savings due to reduced accident frequency is based data from Tabler's (1982) study and though they will be adjusted for inflation, they do not take into account increased traffic volume in the study area which may affect what might be observed today.

5.2.3 Land Holding Costs

Finally, a land holding cost (total value of land plus interest on which the snowfence is constructed) of $0/year will be assumed for the basic analysis of each snowfence scenario. This assumes that there are no opportunity costs associated with establishing a snowfence system on the land. However, land holding costs will be addressed in the sensitivity analysis for each scenario. Land holding costs will be calculated assuming the snowfence system is 100 feet wide (includes fence and space for snowdrift). Both costs per mile and costs per acre will be given when considering varying land holding costs.

5.3 Conversion of Benefits to 1998 dollars

Savings in Snow and Ice Removal Costs

1972 V_o = $4077/mile/year

1998 $V_n = V_o(1.05^{26}) = 4077(1.05^{26})$ = **$14,497/mile/year**

Savings from reduced ground blizzard accidents

22 accidents/year
$3041/accident (1981 estimate)
$66902 savings per year/32.93miles of snowfence V_o =$2032/mile value in 1981
n = number of years from 1981 to 1998 = 17
1998 = $V_n = V_o(1.05^n) = 2032(1.05^{17})$ = **$4657/mile/year**

Savings from reduced wind caused accidents

17 accidents/year
$3041/accident (1981 estimate)
$51697 savings per year/32.93 miles of snowfence V_o =$1570/mile value in 1981
n = number of years from 1981 to 1998 = 17
1998 = $V_n = V_o(1.05^n) = 1570(1.05^{17})$ = **$3599/mile/year**

5.4 Scenario 1: Wyoming Board Fence (all figures are per mile of snowfence and the analysis assumes a useful life of 20 years (Shaw, 1997))

5.4.1 Costs

Establishment cost $87,067.20/mile (Shaw, 1997)
Maintenance costs $2,640/mile/year (Shaw, 1997)

Compounded establishment costs

$V_n = \$87067.2(1.05^{20}) =$ **$231,015/mile**

Compounded total maintenance costs

19 years of maintenance

$V_n = 2640((1.05^{19}-1)/.05) =$ **$80,623/mile**

Total compounded costs = $231,015 + $80,623 = **$311,638/mile**

Present value of total compounded costs

$V_o = V_n(1/(1.05^{20})) = \$311,638(1/(1.05^{20})) =$ **$117,453/mile**

5.4.2 Benefits

Compounded total benefits from snow and ice removal savings

$V_n = \$14,497((1.05^{20}-1)/0.05) =$ **$479,357/mile**

Compounded total benefits from reduced accidents due to ground blizzards

$\$4657 * ((1.05^{20} -1)/.05) =$ **$153,988/mile**

Compounded total benefits from reduced accidents due to wind

$\$3599 * ((1.05^{20} - 1)/.05) =$ **$119,004/mile**

Total compounded benefits = $479,357 + $153,988 + $119,004
= **$752,350/mile**

Present value of total compounded benefits

$V_o = V_n(1/(1.05^{20})) = \$752,350\ (1/1.05^{20})) =$ **$283,553/mile**

5.4.3 Results

Total Net Benefits = $752,350 - $311,638 = **$440,711/mile**
Present Net Benefits = $283,553 - $117,453 = **$166,100/mile**
Benefit-Cost Ratio = $283,553/$117,453= **2.41:1**
SEV = $752,350[1/ $(1.05^{20} - 1)$] = **$266,565/mile**
IRR = $440,711 [1/ $((1+ i)^{20} -1)$] =1.54 or 154%
Annual Breakeven benefit = a = [$117,453 * $(.05(1.05^{20}))]/ (1.05^{20} -1)$ = **$9424/mile/year**

5.4.4 Discussion of Results

The analysis of the Wyoming Board Fence design confirms the thought that this snowfence design is beneficial. Based on the benefits drawn from the I-80 study the Wyoming Board Fence design would provide a total net benefit of $440,711/mile by the end of its useful life. The internal rate of return on the project is 154% which also indicates that it is a good investment. The IRR is so high because annual benefits are being accrued immediately after the snowfence is established.

When looking at the costs of this scenario it can be seen that snowfence establishment comprises the largest portion of the cost burden. The remainder of the total cost goes into maintaining the snowfence (Figure 5.1). Reducing per mile establishment costs will have the greatest impact on improving the economic performance of the snowfence system mainly

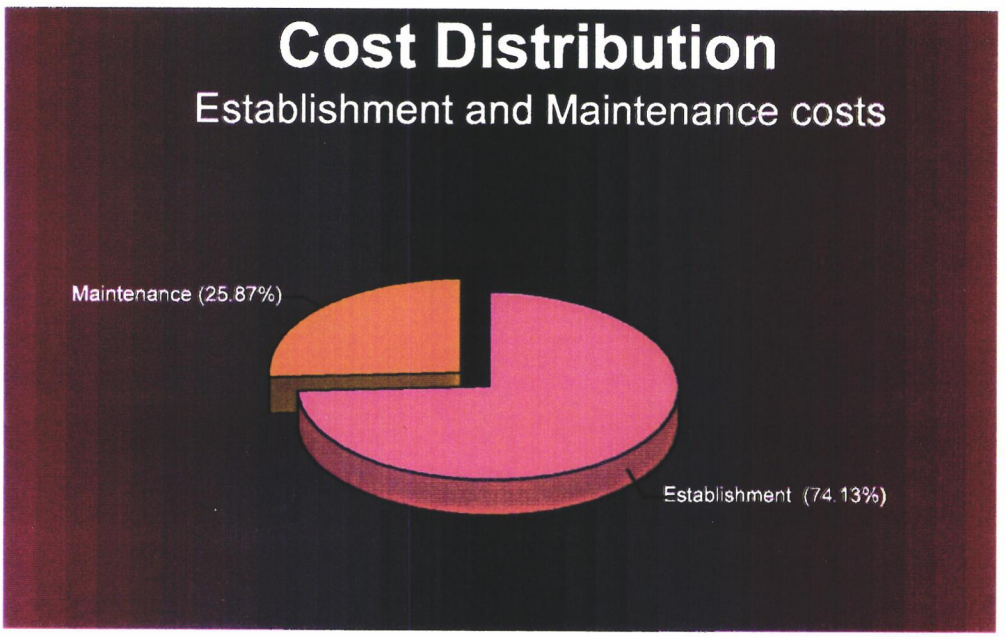

Figure 5.1. Cost Distribution for Wyoming Board Fence Scenario Including Interest

because it is an up-front cost. Reducing the up-front costs of establishment effectively reduces the amount of interest charges the costs incur over time. Maintenance costs may prove to be more difficult to decrease without reducing the overall effectiveness of the snowfence and in turn its utility.

The distribution of benefits shows that more than 64% of the benefits are attributed to savings in snow and ice removal costs (Figure 5.2). The remaining benefits are attributed to a reduction in wind-related (15.82%) and ground blizzard (20.47%) accidents

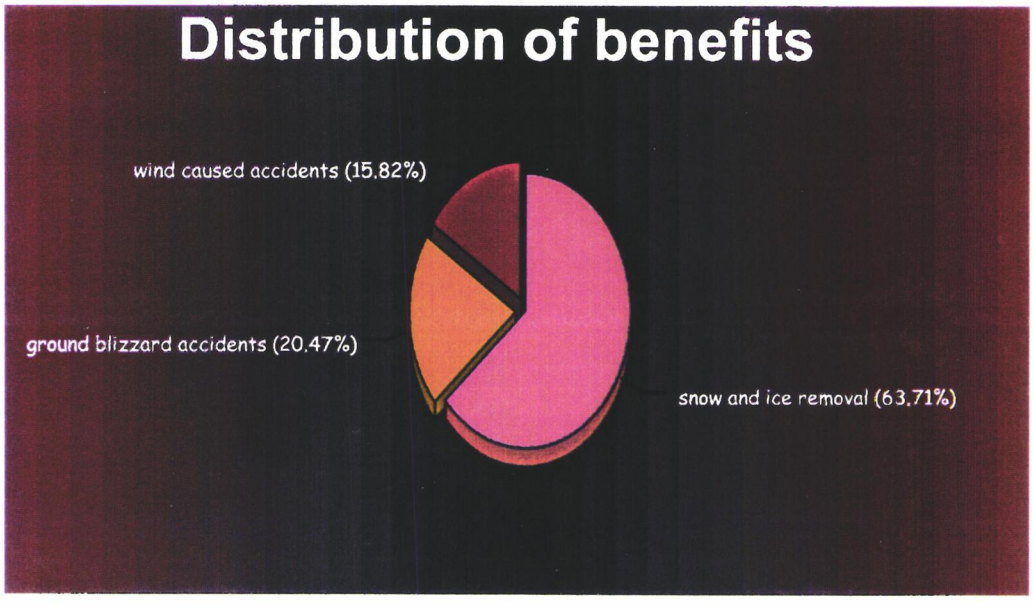

Figure 5.2. Distribution of Total Benefits for the Wyoming Board Fence Scenario Including Interest

The benefit-cost ratio for the scenario is 2.41:1 meaning that the snowfence returns $2.41 in benefits for every $1 spent on the project. A breakeven benefit of $9,424/year was calculated meaning that $9,424 is the amount of annual benefits necessary to cover the total costs (including interest) of the snowfence.

5.4.5 Sensitivity Analysis

Land holding costs

As previously discussed land costs (in this case) are annual payments to private land owners for the right to use their land for the establishment of the snowfence. The amount of annual payment is likely to vary depending upon the value (or the opportunity lost) of the land in question. The following analysis looks at the effects of varying these land rent values on the economic analysis (Table 5.1). As can be seen from Table 5.1 and Figure 5.3, as land holding costs (total annual land costs plus interest) increase the total net benefits, present net benefits, SEV, IRR, and benefit-cost ratio decrease while the breakeven benefits, or benefits needed to cover costs, increase.

Calculation of total land holding costs = 100ft (width) * 5,280 feet = 52800ft^2
52800ft^2 * 1acre/43560ft^2 = 12.12 acres/mile
12.12 acres * \$75/acre = \$909/mile/year
\$909 * ((1.05 ^{20})-1/.05) = **\$30,049/mile**

Table 5.1. Effects of Land Holding Costs on the Economic Analysis of Wyoming Board Fence Scenario

Annual Land Holding Cost (\$/acre)	Total Land Holding Costs *	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
0	0	\$440,711	\$166,100	2.41:1	\$266565	\$9,424	154%
\$75	\$30,049	\$410,663	\$154,775	2.2:1	\$248,390	\$10,333	153%
\$100	\$40,065	\$400,647	\$151,000	2.14:1	\$242,332	\$10,636	152%
\$125	\$50,081	\$390,631	\$147,225	2.08:1	\$236,274	\$10,939	152%
\$150	\$60,097	\$380,614	\$143,450	2.02:1	\$230,215	\$11,242	152%
\$175	\$70,113	\$370,598	\$139,675	1.97:1	\$224,157	\$11,545	151%
\$200	\$80,129	\$360,582	\$135,900	1.92:1	\$218,099	\$11,848	151%

*all values in \$/mile

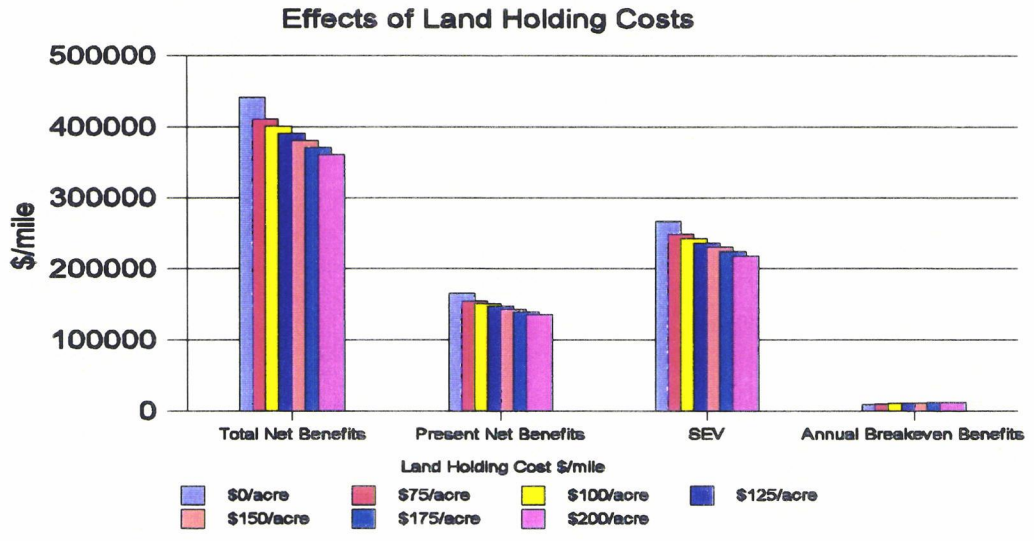

Figure 5.3. Effects of Land Holding Costs on Economic Analysis of Wyoming Board Fence Scenario

Changing the Interest Rate

Variations in the interest rate chosen will have an impact upon the economic results (Table 5.2). As the interest rate rises, there is an increase in the total net benefits and an increase in the breakeven benefits. However, as the interest rate rises the present net benefits, benefit-cost ratio and SEV decline (Figure 5.4). Changing the interest rate has no affect on the IRR.

Table 5.2. Effects of Interest Rate on the Economic Analysis (without land holding costs) of Wyoming Board Fence Scenario

Interest rate	Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
5%	$440,711	$166,100	2.41:1	$266,565	$9,425	154%
6%	$468,620	$146,118	2.27:1	$212,320	$10,014	154%
7%	$497,167	$128,477	2.14:1	$173,248	$10,626	154%
8%	$525,987	$112,850	2.02:1	$143,675	$11,259	154%

*All values in $/mile

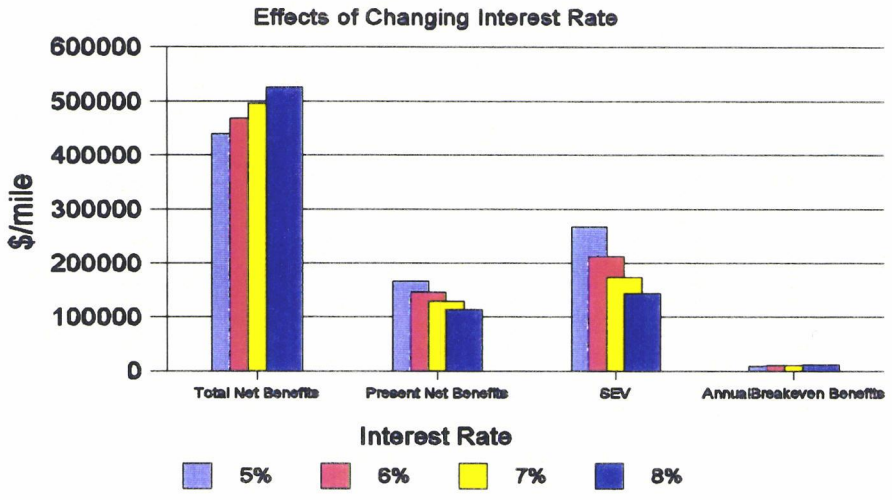

Figure 5.4. Effects of Changing Interest Rate on Economic Analysis of Wyoming Board Fence Scenario

Useful Life

It may be possible to extend the useful life of the artificial snowfence. Any extension beyond the 20 years used for this analysis would change the results (Table 5.3). It is important to note that for each year added to the useful life of the snowfence another year of maintenance is needed. Increasing the useful life of the snowfence results in an increase in the total net and present net benefits, benefit-cost ratio and SEV. There is a decrease in the IRR and annual breakeven benefits (Figure 5.5).

Table 5.3. Effects of Useful Life of the Snowfence on the Economic Analysis of Wyoming Board Fence Scenario

Useful Life (years)	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
20	$440,711	$166,100	2.41:1	$266,565	$9,425	154%
21	$482,860	$173,319	2.46:1	$270,364	$9,235	144%
22	$527,116	$180,195	2.51:1	$273,789	$9,064	135%
23	$573,585	$186,743	2.55:1	$276,890	$8,908	127%
24	$622,377	$192,979	2.60:1	$279,707	$8,768	120%
25	$673,609	$198,919	2.63:1	$282,275	$8,639	114%

*All values in $/mile

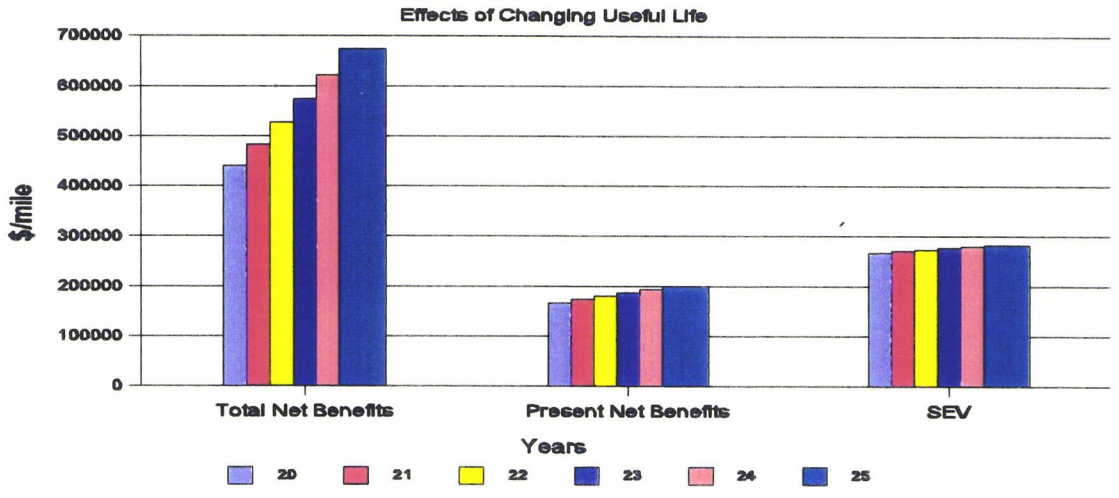

Figure 5.5. Effects of Changing Useful Life on Economic Analysis of Wyoming Board Fence Scenario

5.4.6 Relative Effects of Sensitivity Testing on the Economic Analysis

The results of relative sensitivity analysis indicate that the analysis seems most sensitive to changes in the useful life of the snowfence (Table 5.4). As can be seen from the table, relatively small increases in the useful life of the fence result in substantial increases in the total net benefits and present net benefits. A 50% increase in the useful life of the snowfence results in a 120% increase in total net benefits and a 35% increase in present net benefits. The relative increases in benefit-cost ratio and SEV are less pronounced than the net benefit changes. Breakeven benefits decrease at a relatively lesser rate than useful life rate increases. On the whole, the table indicates that any increase in the useful life of the snowfence translates into an increased economic performance.

Interest rate changes, have a rather dramatic impact on present net values and SEV. For example a 50% increase in the interest rate (from 5% to 7.5%) leads to a 28% decrease in present net benefits and a 41% decrease in the SEV. Like the change in useful life, the relative change in interest rate has a much smaller effect on the other economic analysis criteria.

Increases in land rent values have little relative effect on all of the analysis results. This indicates that paying larger sums of money to those landowners whose land is of high value otherwise but needed for snowfence establishment will not have a major impact on the economic performance of the snowfence.

Table 5.4. Relative Effects of Sensitivity Testing on the Economic Analysis of Wyoming Board Fence Scenario

		% Change					
Base value	% Increase	Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Land Rent $75/acre							
	10%	-1%	-1%	-1%	-1%	+1%	0%
	20%	-2%	-2%	-2%	-2%	+2%	0%
	30%	-2%	-2%	-3%	-2%	+3%	0%
	40%	-3%	-3%	-3%	-3%	+4%	0%
	50%	-4%	-4%	-4%	-4%	+4%	0%
Interest Rate 5%							
	10%	+3%	-6%	-3%	-11%	+3%	0%
	20%	+6%	-12%	-6%	-20%	+6%	0%
	30%	+10%	-18%	-9%	-28%	+10%	0%
	40%	+13%	-23%	-11%	-35%	+13%	0%
	50%	+16%	-28%	-14%	-41%	+16%	0%
Useful Life 20 years							
	10%	+20%	+9%	+4%	+3%	-4%	-12%
	20%	+41%	+16%	+8%	+5%	-7%	-22%
	30%	+65%	+23%	+11%	+7%	-10%	-29%
	40%	+91%	+30%	+13%	+8%	-12%	-35%
	50%	+120%	+35%	+16%	+10%	-14%	-41%

5.5 Scenario 2: Living Snowfence (all values are $/mile and the analysis assumes a useful life of 50 years (Shaw,1997))

This scenario uses cost estimates from the Colorado Interagency Living Snowfence Program estimating costs per mile and maintenance costs for its living snowfence programs (Shaw, 1997). It will be assumed that the snowfence consists of an average of three rows of trees and shrubs. It will be assumed that, for the basic analysis, it will take 20 years before the snowfence incurs any benefits (this will be changed in the sensitivity analysis) and that all of the plantings are done in one year and all mature at the same time. The establishment costs include fencing, fabric mulch and site prep costs.

5.5.1 Costs

Establishment cost $20,434/mile (Shaw, 1997)
Maintenance cost $1,000/mile for the first three years (Shaw, 1997)

Compounded establishment costs

$$V_n = \$20,434(1.05^{50}) = \mathbf{\$234,325/mile}$$

Compounded total maintenance costs

$$V_n = \$1,000((1.05^{3} - 1)/.05)*(1.05^{47}) = \mathbf{\$31,229/mile}$$

Total Compounded Costs =$234,325 + $31,229 = **$265,554/mile**

Present value of total compounded costs

$$V_0 = V_n(1/1.05^{50})) = \$265,554(1/(1.05^{50})) = \mathbf{\$23,157/mile}$$

5.5.2 Benefits

Compounded total benefits from snow and ice removal savings

$$V_n = \$14,497((1.05^{30} - 1)/.05) = \mathbf{\$963,164/mile}$$

Compounded total benefits from reduced accidents due to ground blizzards

$$\$4657((1.05^{30} - 1)/.05) = \mathbf{\$309,406/mile}$$

Compounded total benefits from reduced accidents due to wind

$$\$3599((1.05^{30} - 1/.05) = \mathbf{\$239,113/mile}$$

Total compounded benefits = $963,164 + $309,406 + $239,113
= **$1,511,683/mile**

Present value of total compounded benefits

$$V_0 = V_n(1/(1.05^{50})) = 1,511,683(1/1.05^{50})) = \mathbf{\$131,824/mile}$$

5.5.3 Results

Total Net Benefits = $1,246,130/mile
Present Net Benefits = $108,667/mile
Benefit-Cost Ratio = 5.69:1
SEV = $119,049/mile
IRR = 48%
Annual Breakeven benefit = $1268/mile/year

5.5.4 Discussion of Results

The analysis of the three row living snowfence indicates that this design, like the Wyoming Board Fence design, is economically beneficial. Positive total net benefits totaling $1,246,130/mile, a benefit-cost ratio of 5.69:1, an IRR of 48% and breakeven benefits calculated at $1268/mile/year confirm this assertion.

The cost distribution for this scenario indicates that over 88% of the total compounded costs comes from the establishment costs. The remaining 22% of the costs come from maintenance of the snowfence (Figure 5.6). The large gap between the portion of total compounded costs attributed to each category is largely due to the fact that the maintenance costs are small ($1000/year) and are only incurred for three years immediately following establishment. Since a large portion of the total costs are due to the establishment of the living snowfence efforts to reduce these total costs will have the greatest effect on the economic analysis results.

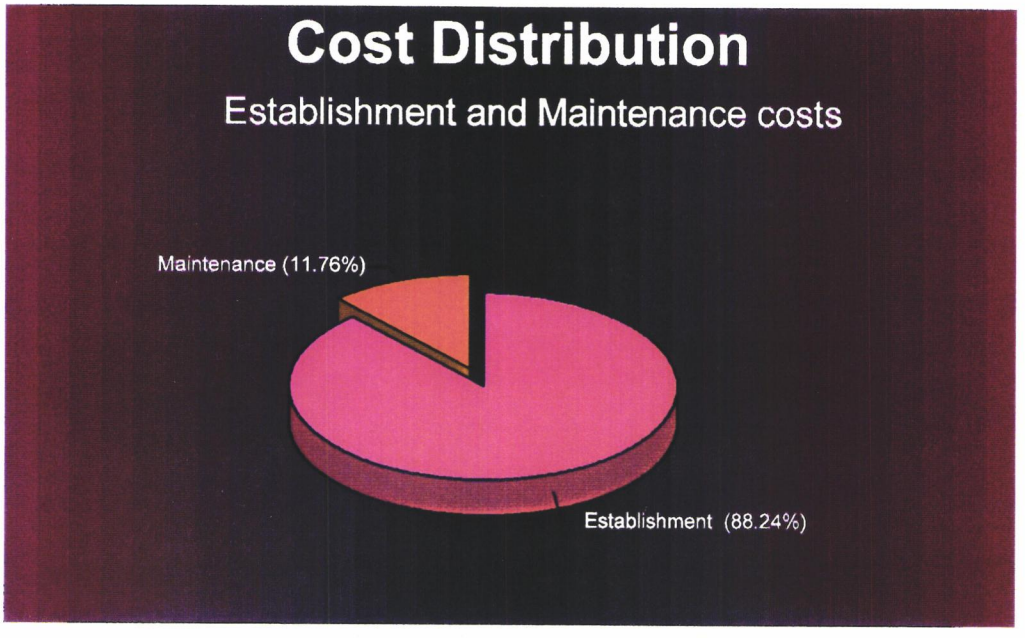

Figure 5.6. Cost Distribution for Living Snowfence Scenario Including Interest

Since the per mile benefits measured for the living snowfence are the same as those for the Wyoming Board Fence design the distribution of benefits over the course of the project are the same. The only factor that is different is the length of time the benefits are observed (20 years for the Wyoming fence vs 30 years for the living snowfence).

Risk is an important factor that has not been incorporated into the analysis. There is a greater risk involved with the living snowfence because there is the possibility that some or all of the trees will die, little or no benefits will be incurred, and the investment will be lost. For this reason, when comparing the living snowfence design to the less risky Wyoming Board Fence design, a higher interest rate (encorporating risk) may be used in evaluating the living snowfence scenario (which is done in the sensitivity analysis).

5.5.5 Sensitivity Analysis

Land Holding Costs

Table 5.5. Effects of Land Holding Costs on the Economic Analysis of Living Snowfence Scenario

Annual Land Holding Costs ($/acre)	Total Land Holding Costs *	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Breakeven Benefits*	IRR
0	0	$1,246,130	$108,667	5.69:1	$119,049	$1,268	48%
$75	$190,244	$1,055,886	$92,077	3.32:1	$100,874	$2,177	47%
$100	$253,659	$992,471	$86,547	2.91:1	$94,815	$2,480	47%
$125	$317,074	$929,056	$81,017	2.59:1	$88,757	$2,783	47%
$150	$380,488	$865,641	$75,487	2.34:1	$82,699	$3,086	47%
$175	$443,903	$802,227	$69,957	2.13:1	$76,640	$3,389	46%
$200	$507,318	$738,812	$64,427	1.96:1	$70,582	$3,692	46%

*all values are $/mile

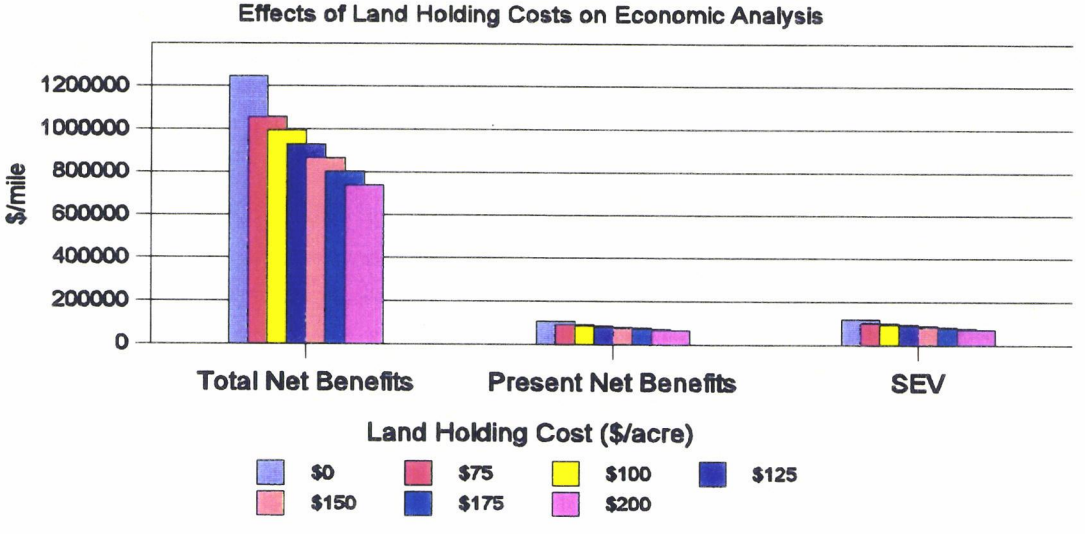

Figure 5.7. Effects of Increasing Land Holding Costs on the Economic Analysis of Living Snowfence Scenario

Increasing land holding costs results in decreasing total and present net benefits, SEV, benefit-cost ratio and IRR while increasing the annual breakeven benefits (Table 5.5 and Figure 5.7).

Changing the Interest Rate

Varying the interest rate used for the analysis has the same effect for this scenario as for the previous one. Increases in interest rate leads to an increase in the total net benefits and the annual breakeven benefits. Present net benefits, SEV, benefit-cost ratio and the IRR decrease as a result of increased interest rate.

Table 5.6. Effects of Interest Rate on the Economic Analysis of Living Snowfence Scenario

Interest rate	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Breakeven Benefits*	IRR
5%	$1,246,130	$108,667	5.69:1	$119,049	$1,268	48%
6%	$1,373,176	$74,547	4.23:1	$78,827	$1,466	48%
7%	$1,470,037	$49,904	3.16:1	$51,658	$1,671	48%
8%	$1,498,275	$31,945	2.39:1	$32,641	$1,881	48%

*All values in $/mile

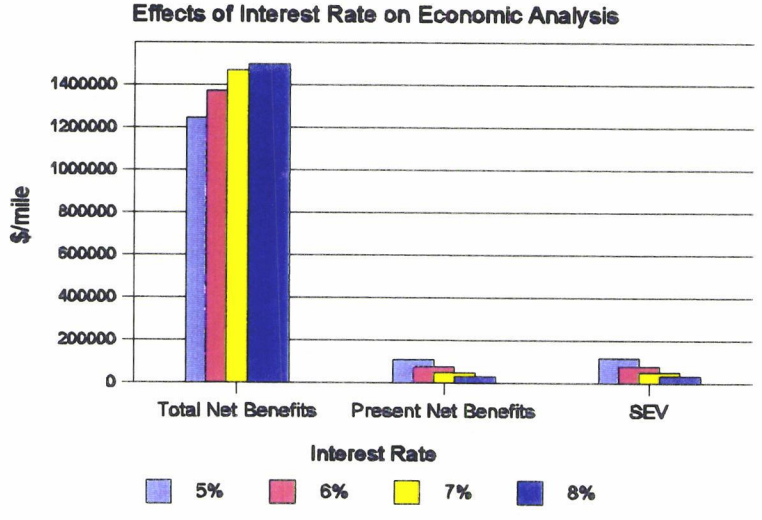

Figure 5.8. Effects of Changing Interest Rate on the Economic Analysis of Living Snowfence Scenario

Effective Life

It is assumed for this scenario that the snowfence will take 20 years to mature an achieve an effective height and full benefits. After this point in time the snowfence has an effective life of 30 years. However, this time to mature will vary with location and site conditions. Many areas in the Great Plains region will experience maturity sooner than the assumed 20 years. This will result in a longer effective life and more benefits. Table 5.7 and Figure 5.9 illustrate the effects that a shorter time to maturity have on the economic analysis. As can be seen in Table 5.7, increasing the effective life of the snowfence greatly increases the total net benefits, present net benefits, SEV, and benefit-cost ratio. This is because by increasing the effective life of the snowfence, more time is generated for benefits to incur for the same cost. For this reason planners should choose species that can thrive on the site and grow quickly so as to generate benefits as soon as possible.

Table 5.7. Effects of Effective Life on Economic Analysis (Assuming a 50 year total lifetime for the Living Snowfence) of Living Snowfence Scenario

Effective Life (years)	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Breakeven Benefits*	IRR
30	$1,246,130	$108,667	5.69:1	$119,049	$1,268	48%
33	$1,556,138	$135,701	6.86:1	$148,665	$1,268	48%
36	$1,915,010	$166,996	8.21:1	$182,950	$1,268	49%
39	$2,330,451	$203,224	9.78:1	$222,639	$1,268	50%
42	$2,811,375	$245,162	11.59:1	$268,584	$1,268	50%
45	$3,368,104	$293,711	13.68:1	$321,771	$1,268	51%

*All values in $/mile

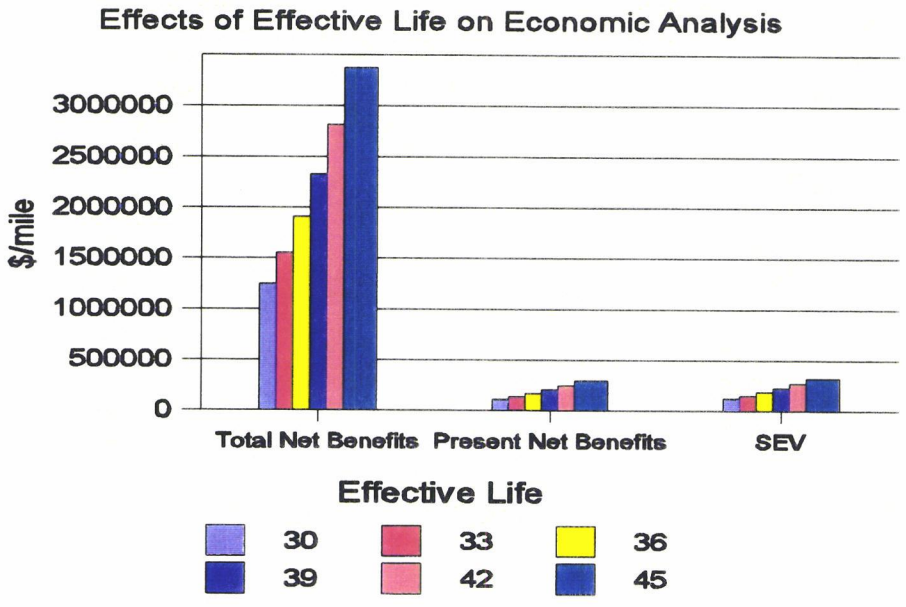

Figure 5.9. Effects of Effective Life on Economic Analysis of Living Snowfence Scenario

5.5.6 Relative Effects of Sensitivity Testing on the Economic Analysis

The living snowfence scenario is very sensitive to changes in the effective life (Table 5.8). The percentage change in the analysis results relative to the percentage changes in effective life are very high and positive. The breakeven benefits remain the same because there is no change in the costs with the extension of the effective life. It can be concluded that efforts to improve the economic performance of the living snowfence is best done by increasing the effective life of the fence through activities such as irrigation, insect and disease control, using long-lived/or fast growing species, and fertilizer.

Increases in the interest rate have large negative effects on the present net benefits, SEV and benefit-cost ratio. Breakeven benefits increase almost proportionately with increases in the interest rate. As the interest rate starts to rise there is an increase in the total net benefits.

Increases in land rent result in relatively smaller and negative (except for breakeven benefits) changes in the analysis results. This indicates that increases in the land rent will not

dramatically affect the economic performance of the snowfence, but the effect it does have will be negative.

Table 5.8. Relative Effects of Sensitivity Analysis on Economic Analysis of Living Snowfence Scenario

		% Change					
Base value	% Increase	Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Land Rent $75/acre							
	10%	-2%	-2%	-4%	-2%	+4%	0%
	20%	-4%	-4%	-8%	-4%	+8%	0%
	30%	-5%	-5%	-11%	-5%	+13%	0%
	40%	-7%	-7%	-14%	-7%	+17%	0%
	50%	-9%	-9%	-17%	-9%	+21%	0%
Interest Rate 5%							
	10%	+5%	-17%	-14%	-19%	+8%	0%
	20%	+10%	-31%	-26%	-34%	+16%	0%
	30%	+15%	-44%	-36%	-46%	+24%	0%
	40%	+18%	-54%	-44%	-57%	+32%	0%
	50%	+20%	-63%	-52%	-65%	+40%	0%
Effective Life 30 years							
	10%	+25%	+25%	+21%	+25%	0%	0%
	20%	+54%	+54%	+44%	+54%	0%	+2%
	30%	+87%	+87%	+72%	+87%	0%	+4%
	40%	+126%	+126%	+104%	+126%	0%	+4%
	50%	+170%	+170%	+140%	+170%	0%	+6%

5.6 Scenario 3: Four-Foot Slatted Snowfence

The third scenario will look at the economic impacts of two four-foot slatted snowfence designs. The first design will be a single-row of four-foot slatted snowfence, and the second will be a double-row four-foot slatted snowfence. It will be assumed that each design incurs full benefits. The double row design is included since it is unlikely that a single-row of a four-foot slatted snowfence will have the same kind of effect on blowing and drifting snow as the artificial snowfence design Tabler (1982) used in his study. Land holding costs will not be considered for this scenario because it is assumed the snowfences are disassembled after every winter and no land is taken out of production.

Cost Data

The cost data for the four-foot slatted snowfence is taken from Dan Perko's, "To Catch the Snow" (1984), that lists 1982 slatted snowfence establishment and maintenance cost estimates. As with the benefits derived from Tabler's study these cost estimates need to be adjusted for average yearly inflation to reflect 1998 dollars. The maintenance costs used include the costs of putting up and removing the snowfence every year along with routine upkeep of the fence. Costs for the double row design are assumed to be double that of the single row design.

Conversion of establishment and maintenance costs to 1998 dollars

Establishment costs

1982 V_o = \$6,400/mile

1998 V_n = \$6,400(1.05 ^{16}) = **\$8,168/mile**

Maintenance costs

1982 V_o = \$2,000/mile/year

1998 V_n = \$2,000(1.05 ^{16}) = **\$4,366/mile/year**

5.6.1 Single row costs (all figures are per mile of snowfence and the analysis assumes a useful life of 8 years)

Establishment cost $8,168/mile
Maintenance cost $4,366/mile/year

Compounded establishment costs

$$V_n = \$8,168(1.05^{8}) = \textbf{\$12,067/mile}$$

Compounded maintenance costs

$$V_n = \$4,366((1.05^{8}-1)/.05) = \textbf{\$41,691/mile}$$

Total compounded costs = $12,067 + $41,691 = **$53,759/mile**

Present Value of total compounded costs

$$V_o = \$53,758(1/1.05^{8})) = \textbf{\$36,386/mile}$$

5.6.2 Benefits (all figures are per mile of snowfence and the analysis assumes a useful life of 8 years)

Compounded total benefits from snow and ice removal savings

$$V_n = \$14,497((1.05^{8}-1)/.05) = \textbf{\$138,433/mile}$$

Compounded total benefits from reduced accidents due to ground blizzards

$$\$4657 * ((1.05^{8}-1)/.05) = \textbf{\$44,470/mile}$$

Compounded total benefits from reduced accidents due to wind

$$\$3599 * ((1.05^{8}-1)/.05) = \textbf{\$34,367/mile}$$

Total compounded benefits = $138,433 + $44,470 + $34,367 = **$217,271/mile**

Present value of total compounded benefits

$$V_o = \$217,271(1/1.05^{8}) = \textbf{\$147,057/mile}$$

5.6.3 Results

Total Net Benefits = $163,512/mile
Present Net Benefits = $110,671/mile
Benefit-Cost Ratio = 4.04:1
SEV = $85,104[1/(1.05^8 -1)] = $342,465/mile
IRR = 809%
Annual Breakeven Benefits = $5,630/mile/year

5.6.4 Discussion of Results

This results indicate positive total and present net benefits, benefit-cost ratio and SEV. The IRR is extremely high because the snowfence is incurring a large amount of net benefits in only 8 years. The annual savings from snow and ice removal are enough to cover the costs of the snowfence.

The analysis of this snowfence design should be considered a best case scenario for the following reasons. It is unlikely that a fence of this height will incur such high snow and ice removal savings because it is likely to reach its full snow storage capacity early in the winter allowing excess snow to drift on roads. The accident benefits are also likely to be less due to the fact that the decreased height provide less protection from wind and blowing snow and therefore have less effect on wind- and ground blizzard related accidents.

Thus, the results should be looked upon for comparison purposes only to see how the design relates to others economically. The two row design is a more realistic way of evaluating the economic performance of the four foot slatted snowfence design and will be discussed next along with a sensitivity analysis. It is not possible to prorate the benefits for height because the relationship between the height and amount of benefits incurred is not known.

5.6.5 Double row costs (all figures are per mile of snowfence and the analysis assumes a useful life of 8 years)

Establishment cost \$8,168/mile/row
2 * \$8,168 = \$16,336/mile
Maintenance cost \$4,366/mile/year/row
2 * \$4,336 = \$8,672/mile
Compounded establishment costs
$V_n = \$16{,}336(1.05^{8}) =$ **\$24,136/mile**

Compounded maintenance costs
$V_n = \$8{,}672((1.05^{8}-1)/.05) =$ **\$82,810/mile**

Total compounded costs = $24,136 + $82,810 = **$106,946/mile**

Present Value of total compounded costs

$$V_o = \$106,946(1/1.05^{8}) = \textbf{\$72,385/mile}$$

5.6.6 Benefits (all figures are per mile of snowfence and the analysis assumes a useful life of 8 years)

Compounded total benefits from snow and ice removal savings

$$V_n = \$14,497((1.05^{8} - 1)/.05) = \textbf{\$138,433/mile}$$

Compounded total benefits from reduced accidents due to ground blizzards

$$\$4657 * ((1.05^{8} - 1)/.05) = \textbf{\$44,470/mile}$$

Compounded total benefits from reduced accidents due to wind

$$\$3599 * ((1.05^{8} - 1)/.05) = \textbf{\$34,367/mile}$$

Total compounded benefits = $138,433 + $44,470 + $34,367 = **$217,271/mile**

Present value of total compounded benefits

$$V_o = \$217,271(1/1.05^{8}) = \textbf{\$147,057/mile}$$

5.6.7 Results

Total Net Benefits = $110,325/mile
Present Net Benefits = $74,672/mile
Benefit-Cost Ratio = 2.03:1
SEV = $31,918[1/(1.05^8 -1)] = $231,069/mile
IRR = 765%
Annual Breakeven Benefits = $11,200/mile/year

5.6.8 Discussion of Results

In comparison to the single-row configuration, the double-row design results in lower total and present net benefits, benefit-cost ratio, SEV, IRR and an increased annual breakeven benefit. The reasoning for this is that the double-row design is double the costs of the single-row design but they both are assumed to have the same benefits. The double row design seems to be more realistic when applying it to Tabler's study area and the benefits incurred in those particular conditions.

The cost distribution of this design shows that over 77% of the total compounded costs for the snowfence are attributed to maintenance costs (maintenance costs include cost of installing and removing the snowfence every year)(Figure 10). Finding more efficient ways of

assembling and dismantling the fence annually is one way to improve the overall economic performance and reduce total costs of the fence.

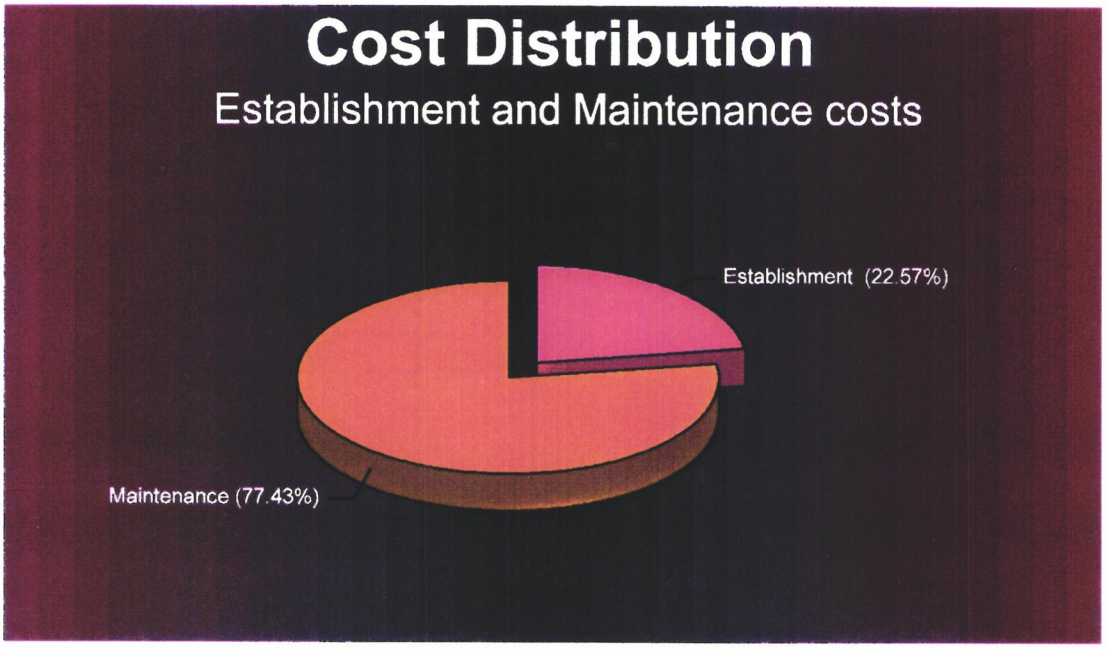

Figure 5.10. Cost Distribution for Double-row Four Foot Slatted Snowfence Scenario Including Interest

5.6.9 Sensitivity Analysis

Changing Interest Rate

Increasing the interest rate results in an increase in the total net benefits (Table 5.9). The present net benefits, benefit-cost ratio, SEV and IRR are all decreasing and the breakeven benefits are increasing.

Table 5.9. Effects of Changing Interest Rate on Economic Analysis of Double-row Four Foot Slatted Snowfence Scenario

Interest rate	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Breakeven Benefits*	IRR
5%	$110,325	$74,672	2.03:1	$231,069	$11,200	765%
6%	$113,329	$71,104	2.01:1	$190,839	$11,303	765%
7%	$116,400	$67,746	1.99:1	$162,075	$11,408	765%
8%	$119,538	$64,582	1.98:1	$140,479	$11,515	765%

*all values are $/mile

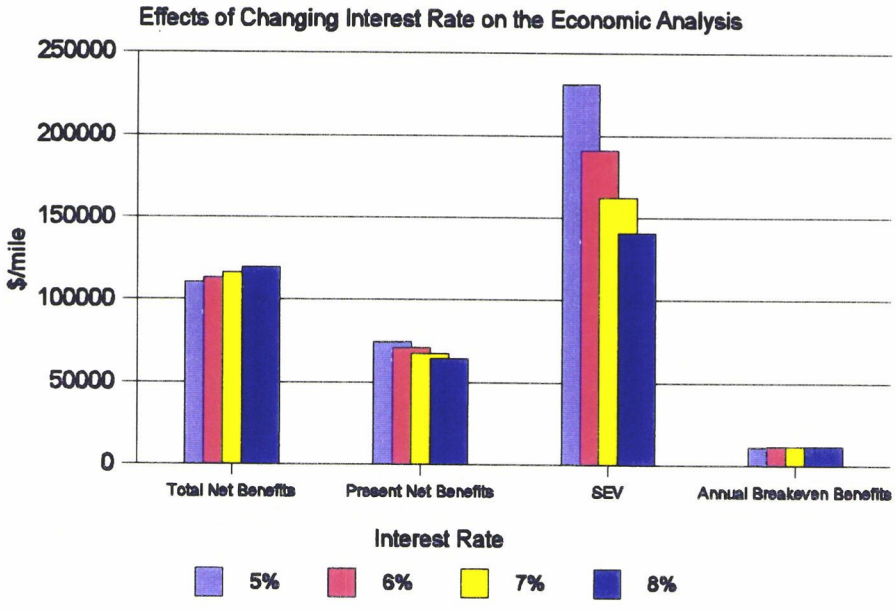

Figure 5.11. Effects of Changing Interest Rate on the Economic Analysis of Double-row Four Foot Slatted Snowfence Scenario

Useful Life

The 8-year useful life used in the initial analysis of the slatted snowfence design is probably a maximum. The fences have been found to typically last an average of 5 to 7 years (Perko, 1984). Decreasing the useful life from 8 to 5 has a negative impact on all of the analysis results (Table 5.10 and Figure 12) except for IRR and annual breakeven benefits. The IRR is not a true indicator of the snowfences' economic performance because the time-frame that benefits are evaluated over in calculating the IRR is so short that an unreasonably large interest rate is calculated for the IRR.

Table 5.10. Effects of Changing Useful Life on the Economic Analysis of Double-row Four Foot Slatted Snowfence Scenario

Useful Life (years)	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
8	$110,325	$74,672	2.03:1	$231,069	$11,200	765%
7	$91,661	$65,142	1.98:1	$225,156	$11,495	1047%
6	$73,886	$55,135	1.91:1	$217,250	$11,890	1562%
5	$56,957	$44,627	1.83:1	$206,156	$12,445	2668%

*all values are $/mile

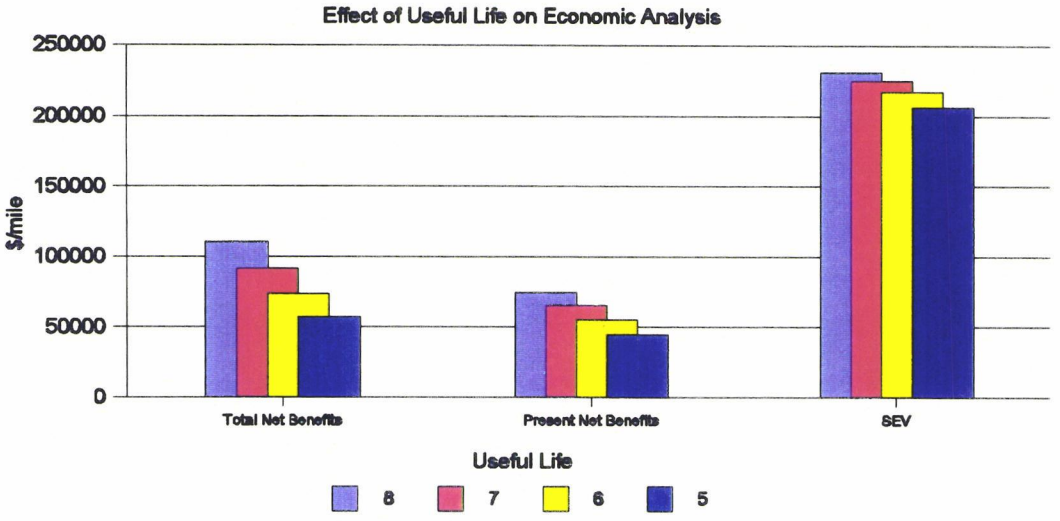

Figure 5.12. Effects of Changing Useful life on the Economic Analysis of Double-row Four Foot Slatted Snowfence Scenario

5.6.10 Relative Effects of Sensitivity Testing on the Economic Analysis

Evaluating the relative sensitivity of changing factors indicates that the analysis is most sensitive to changes in useful life (Table 5.11). Small increases in useful life result in relatively large increases in the economic criteria values. This analysis demonstrates the impact of extending the useful life of the snowfence in order to attain more benefits. Also as the useful life increases the IRR declines sharply because benefits and costs are being spread out over a longer period of time.

Changes in the interest rate have a relatively small impact on all of the results of the economic criteria except SEV. Increases in the interest rate have a large negative impact on the SEV.

Table 5.11. Relative Effects of Sensitivity Testing on the Economic Analysis of Double-row Four Foot Slatted Snowfence Scenario

Base value	% Increase	% Change					
		Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Interest Rate 5%							
	10%	+1%	-2%	-1%	-10%	+0%	0%
	20%	+1%	-4%	-1%	-18%	+1%	0%
	30%	+2%	-6%	-1%	-24%	+1%	0%
	40%	+2%	-7%	-2%	-30%	+2%	0%
	50%	+2%	-9%	-2%	-35%	+2%	0%
Useful Life 5 years							
	10%	+15%	+12%	+2%	+3%	-2%	-28%
	20%	+30%	+24%	+5%	+5%	-5%	-44%
	30%	+45%	+35%	+7%	+7%	-6%	-54%
	40%	+61%	+46%	+8%	+9%	-8%	-62%
	50%	+77%	+57%	+10%	+11%	-9%	-68%

5.7 Scenario 4: Combination Four-foot Slatted Snowfence and Living Snowfence

The last scenario concentrates on a design combining the double-row four-foot slatted snowfence with the living snowfence design. The goal of this design is to provide immediate protection to the road while the living snowfence establishes itself. When the trees are planted, the slatted snowfence is installed to protect the road. As soon as the living snowfence becomes fully effective the slatted snowfence is removed.

This scenario assumes that the two rows of slatted snowfence are enough protection to incur full benefits. The sensitivity analysis will include land holding costs because even though the slatted snowfence is removed every year the living snowfence takes land out of production. It will be this area that the living snowfence uses that will go into calculating the land holding costs. It will be assumed that the living snowfence will take 20 years to attain full effective height (this means that the slatted snowfence will be used for 20 years) and that the useful life of the entire project is 50 years. The slatted snowfence will be replaced every 5 years meaning there will be a total of 4 slatted snowfences used before the living snowfence becomes effective.

5.7.1 Costs

Double-row slatted snowfence (one 2-row fence)

Establishment cost $8,168/mile/row

$2 * \$8,168 = \$16,336$/mile

Maintenance cost $4,366/mile/year/row

$2 * \$4,336 = \$8,672$/mile

Total Compounded Establishment Costs (for 2-row fences with 5 years useful life)

$V_n = \$16,336[(1.05^{50}) + (1.05^{45}) + (1.05^{40}) + (1.05^{35})] =$ **$539,225/mile**

Total Compounded Maintenance Costs

$V_n = \$8,672[(1.05^{20} - 1)/.05]*(1.05^{30}) =$ **$1,239,308/mile**

Living Snowfence

Establishment cost $20,434/mile (Shaw, 1997)

Maintenance cost $1,000/mile for the first three years (Shaw, 1997)

Total Compounded Establishment Costs

$V_n = \$20,434(1.05^{50}) =$ **$234,325/mile**

Total Compounded Maintenance Costs

$V_n = \$1,000((1.05^{3} - 1)/.05)*(1.05^{47}) =$ **$31,229/mile**

Total Compounded Costs

$539,225 + $1,239,308 + $234,325 + $31,229 =**$2,044,087/mile**

Present Value of total costs

V_o = $2,044,087(1/1.05 ^{50})) = **$178,252/mile**

5.7.2 Benefits

Compounded total benefits from snow and ice removal savings

V_n = $14.497(1.05 ^{50}-1)/.05= **$3,034,918/mile**

Compounded total benefits from reduced accidents due to ground blizzards

V_n = $4,657(1.05 ^{50}-1)/.05= **$974,934/mile**

Compounded total benefits from reduced accidents due to wind

V_n = $3,599(1.05 ^{50}-1)/.05= **$753,443/mile**

Total compounded benefits

$3,034,918 + $974,934 + $753,443 = **$4,763,295**

Present Value of total compounded benefits

V_o= $4,763,295(1/1.05 ^{50})) = **$415,377/mile**

5.7.3 Results

Total Net Benefits = $4,763,295 - $2,044,087 = **$2,719,208/mile**
Present Net Benefits = $415,377 - $178,252 = **$237,125/mile**
Benefit-Cost Ratio = 2.33:1
SEV = $259,779/mile
IRR = 50%
Annual Breakeven Benefits = $9,764

5.7.4 Discussion of Results

The analysis results for this combination of the slatted snowfence with the living snowfence provide an economically sound solution for managers who want to stem the problem of blowing and drifting snow immediately but still get the long service life of the living snowfence. The analysis results in positive total and present net benefits and SEV. A benefit-cost ratio of 2.33:1 indicates that the benefits outweigh the costs and an IRR of 50% is a promising return on investment considering the costs and benefits are carried over 50 years.

The cost distribution of the snowfence system shows that 60.63% of the total costs (including interest) are attributed to maintaining the slatted snowfence until the living snowfence matures (Figure 13). Overall about 87% of the total costs are due to establishment and maintenance of the slatted snowfence. These results indicate that efforts to reduce costs will have the most impact if they are concentrated on the slatted snowfence system.

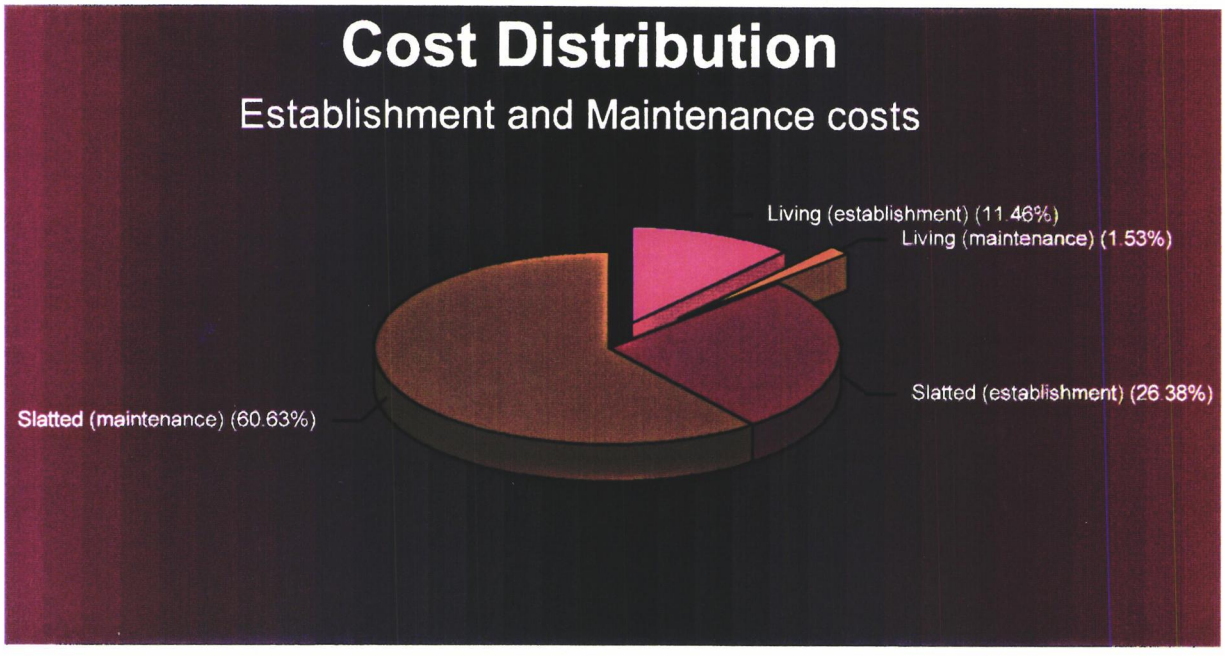

Figure 5.13. Cost Distribution of Combination Slatted and Living Snowfence Scenario (Including Interest)

5.7.5 Sensitivity Analysis

Land Holding Costs

Land holding costs are being considered in this scenario because the living snowfence will take areas of land out of potential agricultural production. It will be assumed that there are no land holding costs associated with the slatted snowfences. An increase in the per acre land rent causes a drop in the total net and present net benefits along with decreases in the benefit-cost ratio, SEV and IRR. Increases in land rent also cause annual breakeven benefits to increase (Table 5.12).

Table 5.12. Effects of Land Holding Costs on the Economic Analysis of Combination Slatted and Living Snowfence Scenario

Annual Land Holding Cost ($/acre)	Total Land Holding Costs *	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
0	0	$2,719,208	$237,125	2.33:1	$259,779	$9,764	50%
$75	$190,244	$2,528,964	$220,535	2.13:1	$241,604	$10,673	50%
$100	$253,659	$2,465,549	$215,005	2.07:1	$235,546	$10,976	50%
$125	$317,074	$2,402,134	$209,475	2.02:1	$229,478	$11,279	50%
$150	$380,488	$2,338,720	$203,945	1.96:1	$223,429	$11,582	50%
$175	$443,903	$2,275,305	$198,415	1.91:1	$217,371	$11,884	50%
$200	$507,318	$2,211,890	$192,855	1.87:1	$211,312	$12,187	49%

*all values are $/mile

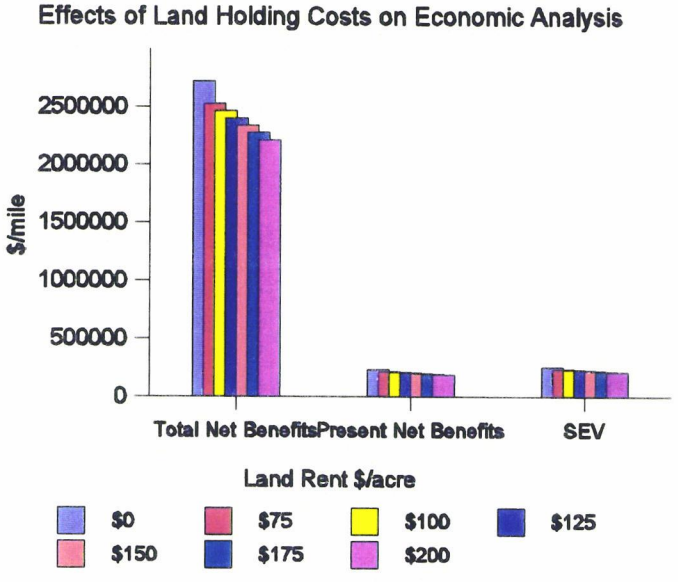

Figure 5.14. Effects of Land Holding Costs on the Economic Analysis of Combination Slatted and Living Snowfence Scenario

Changing the Interest Rate

Increases in the interest rate cause a rise in the total net benefits and breakeven benefits, while the present net benefits, SEV and benefit-cost ratio decline (Table 5.13). However, the rate of increase of the total net benefits becomes greater as the interest rate increases. Conversely, the rate of decline in the present net benefits, SEV and benefit-cost ratio, as interest rate increases, is declining.

Table 5.13. Effects of Changing Interest Rate on Economic Analysis of Combination Slatted and Living Snowfence Scenario

Interest rate	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Breakeven Benefits*	IRR
5%	$2,719,208	$237,125	2.33:1	$259,779	$9,764	50%
6%	$3,528,820	$191,574	2.15:1	$202,571	$10,599	50%
7%	$4,620,927	$156,870	2.00:1	$162,383	$11,386	50%
8%	$6,098,330	$130,024	1.88:1	$132,857	$12,124	50%

*all values are $/mile

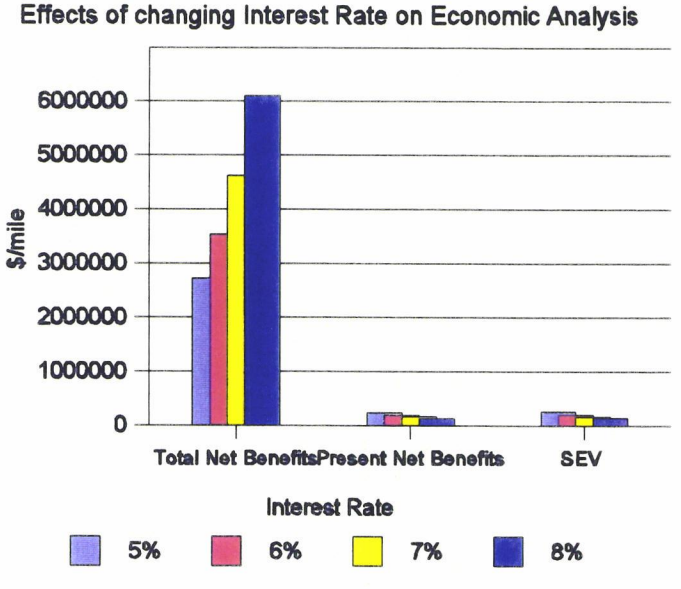

Figure 5.15. Effects of Changing Interest Rate on Economic Analysis of Combination Slatted and Living Snowfence Scenario

Effective Life

As previously discussed the majority of the costs for this snowfence design are a direct result of the slatted snowfence. Thus, it can be concluded that increasing the effective life of the living snowfence costs will be reduced significantly through decreasing the amount of time necessary to maintain the slatted snowfence. This part of the sensitivity analysis will focus on decreasing the amount of time necessary for the living snowfence to become fully effective, thereby reducing the amount of maintenance time and costs incurred for the slatted snowfence. In some cases the time to reach maturity will be decreased enough that one cycle of slatted snowfence can be eliminated (one cycle of slatted snowfence is assumed to be 5 years). For example, the scenario used so far assumes that the slatted snowfence is replaced 3 times before the living snowfence is fully effective. Reducing the time to maturity for the living snowfence to 15 years means that the slatted snowfence only has to be replaced two times. Hopefully, placing the slatted snowfence upwind of the living snowfence will result in snowdrifts from the slatted snowfence that provides additional moisture to the living snowfence. This may aid in speeding up the time to maturity for the living snowfence in areas where moisture is a limiting factor.

As the effective life of the living snowfence is increased there is an increase in the total net and present net benefits, SEV, benefit-cost ratio and IRR, along with a decrease in the annual breakeven benefits (Table 5.14). The increase is greatest for those changes which eliminate the need for a replacement of the slatted snowfence. These results point out the importance of improving the growth rate of the living snowfence or using fast-growing species to eliminate expenditures on the slatted snowfence.

Table 5.14. Effects of Effective Life on Economic Analysis of Combination Slatted and Living Snowfence Scenario

Living Snowfence							
Effective Life (years)	Cycles of slatted snowfencing	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
30	4	$2,719,208	$237,125	2.33:1	$259,779	$9,764	50%
33	4	$2,837,363	$247,429	2.47:1	$271,067	$9,200	50%
36	3	$3,064,253	$267,214	2.80:1	$292,742	$8,116	50%
39	3	$3,222,592	$281,022	3.09:1	$307,869	$7,360	51%
42	2	$3,520,895	$307,035	3.83:1	$336,368	$5,935	51%
45	1	$3,879,864	$338,339	5.39:1	$370,662	$4,220	51%

*all values are $/mile

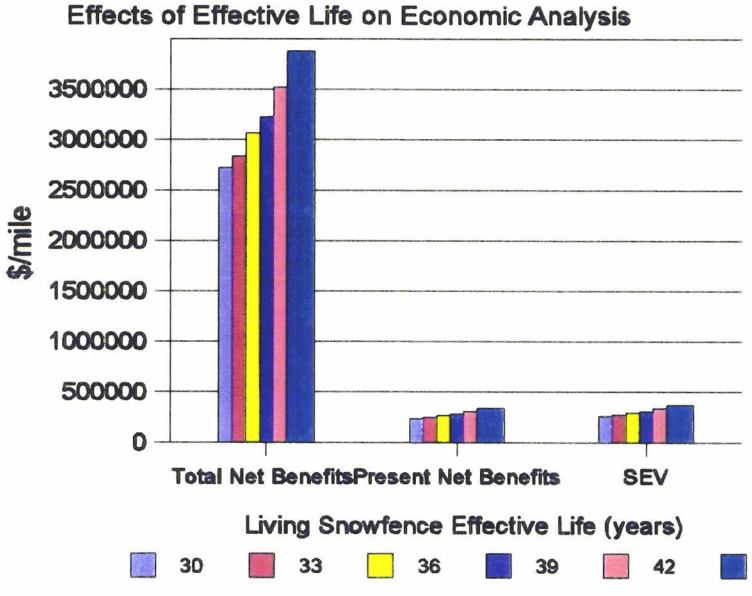

Figure 5.16. Effects of Effective Life on Economic Analysis of Combination Slatted and Living Snowfence Scenario

5.7.6 Relative Effects of Sensitivity Testing on Economic Analysis

The analysis seems most sensitive to increases in interest rate and changes in the effective life of the living snowfence (Table 5.15). As the interest rate increases, there is a relatively larger increase in the total net benefits. The present net benefits and SEV seem to decline at relatively the same rate as the increase in interest rate. Increasing the effective life leads to relatively larger increases in the benefit-cost ratio. The analysis seems least sensitive to changes in land rent values. Relatively large changes in land rent result in small changes in the analysis. Total and present net benefits along with the SEV seem to be most affected by changes in the land rent.

These results indicate where and how changes in management strategies will affect the economic performance of the fence. If private landowners begin demanding more for land taken out of production due to the snowfences, managers can see that increased land rents will have a minor (but negative) effect on the economic performance of the fence. Increased interest rates have the potential to dramatically reduce the net benefits of the snowfence system. Increasing the effective life of the living snowfence has the greatest impact on the economic performance of the snowfence system. By choosing faster growing or longer living trees and by using fertilizers to speed up growth, managers have the opportunity to dramatically reduce the costs of maintaining and replacing the slatted snowfence during the living snowfence maturing time frame.

Table 5.15. Relative Effects of Sensitivity Testing on Economic Analysis of Combination Slatted and Living Snowfence Scenario

		% Change					
Base value	% Increase	Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Land Rent $75/acre							
	10%	-1%	-1%	-1%	-1%	+1%	0%
	20%	-2%	-2%	-2%	-2%	+2%	0%
	30%	-2%	-2%	-2%	-2%	+3%	0%
	40%	-3%	-3%	-3%	-3%	+3%	0%
	50%	-4%	-4%	-4%	-4%	+4%	0%
Interest Rate 5%							
	10%	+14%	-10%	-4%	-12%	+4%	0%
	20%	+30%	-19%	-8%	-22%	+9%	0%
	30%	+48%	-27%	-11%	-30%	+13%	0%
	40%	+70%	-34%	-14%	-38%	+17%	0%
	50%	+95%	-40%	-17%	-44%	+21%	0%
Effective Life 30 years							
	10%	+4%	+4%	+6%	+4%	-6%	0%
	20%	+13	+13	+20%	+13	-17%	0%
	30%	+19%	+19	+33%	+19	-25%	+2
	40%	+30%	+3%	+65%	+30%	-39%	+2%
	50%	+43%	+43%	+131%	+43%	-57%	+2%

CHAPTER 6 DISCUSSION OF SCENARIOS AND ANALYSIS RESULTS

6.1 Introduction

All of the case studies analyzed resulted in positive total and present net benefits, SEV, IRR and benefit-cost ratios greater than one. These results indicate that all of the designs studied are viable economic options. This section will look at the differences in economic performance of the scenarios.

6.2 Analysis Results

At the beginning of each scenario there is a basic analysis of the economic performance of each design. These analyses results are summarized in Table 6.1.

Table 6.1. Summary of the Analysis Criteria for Each Snowfence Scenario

	Analysis Criteria					
Scenario	Total Net Benefits*	Present Net Benefits*	Benefit-Cost Ratio	SEV*	Annual Breakeven Benefits*	IRR
Wyoming board fence	$440,711	$166,100	2.41:1	$266,565	$9,424	154%
Living snowfence	$1,246,130	$108,667	5.69:1	$119,049	$1,268	48%
Slatted snowfence (2-row)	$110,325	$74,672	2.03:1	$231,069	$11,200	765%
Combination slatted and living snowfence	$2,719,208	$237,125	2.33:1	$259,779	$9,764	50%

*all values are $/mile

The slatted snowfence is out performed in every category except the IRR in which it has an irregularly high value mainly because the project is over 8 years. The combination slatted and living snowfence scenario compares very well with the others. It has high total and present net benefits and SEV with the only major drawback being the high annual breakeven benefits. The high breakeven benefits are a result of the expenses associated with the slatted snowfence

portion of the scenario. The Wyoming board fence performs very well despite its high establishment costs. Finally, the living snowfence scenario also compares well with the others. It has the highest benefit-cost ratio, the lowest annual breakeven benefits and the rest of its analysis criteria compare favorably with the others.

6.2.1 Cost Distribution

In reviewing each scenario's total cost distributions it is clear the four scenarios can be divided up into two groups (Figure 6.1). The first group is the Wyoming board fence and living snowfence scenarios and the second includes the slatted snowfence and combination slatted and living snowfence. In the first group, the greatest portion of the total costs are attributed to the snowfence's establishment and in the second group the greatest portion of the costs are due to maintenance of the snowfence.

The reason for such high value percentage establishment for the living snowfence is because annual maintenance costs are so small ($1,000/mile/year) compared to the other designs ($2,640/mile/year for Wyoming board fence and $8,672/mile/year for double-row four foot slatted snowfence). Furthermore, maintenance costs are only for the first three years of the living snowfence's lifetime.

High annual maintenance costs are the primary reason for the cost distributions of the slatted snowfence and combination slatted and living snowfences being weighted so heavily toward maintenance. In the case of the combination slatted and living snowfence only 1.53% of the total costs comes from maintenance of the living snowfence while the rest is attributed to the slatted snowfence.

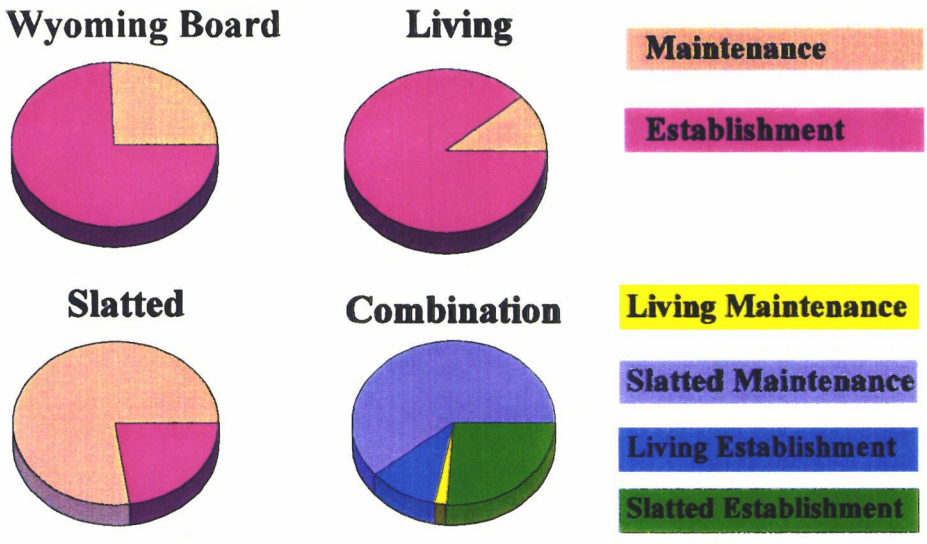

Figure 6.1. Cost Distributions (Including interest)

The cost distribution results provide an opportunity for managers to determine the best way to improve the economic performance of the snowfence system. Identifying the major cost area enables managers to identify the options that will have the greatest effect on reducing costs.

6.2.2 Sensitivity Analysis

To evaluate how the effects of changes in the analysis variables (land holding costs, interest rate and effective life) differ between the four scenarios, results of the Relative Effects of Sensitivity Testing on the Economic Analysis will be compared at the 50% change level.

6.2.3 Land Holding Costs

In the three scenarios where land holding costs are considered (Wyoming board fence, Living snowfence, and Combination slatted and living snowfence) there are a few differences in the resulting analysis criteria. Table 6.3 shows how a 50% increase in land rent (50% increase from 75$/acre) affects the three scenario's analysis criteria.

Table 6.2. Effects of a 50% Increase in Land Holding Costs on the Scenario Analysis Criteria

	% Change					
Scenario	Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Wyoming board fence	-4%	-4%	-4%	-4%	+4%	0%
Living snowfence	-9%	-9%	-17%	-9%	+21%	0%
Combination slatted and living snowfence	-4%	-4%	-4%	-4%	+4%	0%

The analysis shows that the 50% increase in the land holding costs has the same effect on the Wyoming board fence and the combination slatted and living snowfence. The reason for this is that for both of these scenarios the total land holding costs and the number of years that the fences receive benefits are equal. The slight differences are mainly due to differences in establishment and maintenance costs.

A 50% increase in land holding costs has a greater effect on the living snowfence scenario for a couple of reasons. First the land holding costs are carried out for 50 years and second, the snowfence only incurs benefits for 30 years. These factors lead to a greater change in the living snowfence analysis criteria with changes in this variable. In all three scenarios, an increase in the land holding costs resulted in a decline in the economic performance of the snowfence.

6.2.4 Interest Rate

A 50% increase in the interest rate had varying effects on the four scenarios, as shown in Table 6.4. In the case of the Wyoming board fence, living snowfence and combonation slatted and living snowfence, the increase in the interest rate caused for a major decline in the economic performance of the systems, especially in the present net benefits, benefit-cost ratio and SEV. For all of the scenarios the increase in the interest rate actually caused the total net benefits to increase, but led to a decline in the overall economic performance of the fences. The increased interest rate affected the slatted snowfence the least, mainly because of the projects short life span (8 years).

Table 6.3. Effects of a 50% Increase in Interest Rate on the Scenario Analysis Criteria

	% Change					
Scenario	Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Wyoming board fence	+16%	-28%	-14%	-41%	+16%	0%
Living snowfence	+20%	-63%	-52%	-65%	+40%	0%
Slatted snowfence	+2%	-9%	-2%	-35%	+2%	0%
Combination slatted and living snowfence	+95%	-40%	-17%	-44%	+21%	0%

6.2.5 Effective Life

Increases in effective life for the two scenarios with living snowfences meant that an increase in the effective life was a decrease in the time it takes for the trees to become effective as a snowfence (the project lifetime remained 50 years). For the other two scenarios, an increase in the effective life meant an increase in the project's lifetime. As can be seen from Table 6.5, increases in the effective life of the project have a dramatic effect on all the analysis criteria.

Table 6.4. Effects of a 50% Increase in the Effective Life on the Scenario Analysis Criteria

	% Change					
Scenario	Total Net Benefits	Present Net Benefits	Benefit-Cost Ratio	SEV	Annual Breakeven Benefits	IRR
Wyoming board fence	+120%	+35%	+16%	+10%	-14%	-41%
Living snowfence	+170%	+170%	+140%	+170%	0%	+6%
Slatted snowfence	+77%	+57%	+10%	+11%	-9%	-68%
Combination slatted and living snowfence	+43%	+43%	+131%	+43%	-57%	+2%

All of the scenarios experienced a dramatic increase in the values of the analysis criteria with one exception. The annual breakeven benefits did not decrease in the living snowfence scenario because an increase in useful life did not have any effect on the total costs of the project, and the lifetime of the project remained constant. Another item to note is that the IRR of the slatted snowfence scenario decreases sharply due to the increase in effective life, mainly because the project has such a short useful life that adding another year greatly decreases average annual values which would affect the IRR.

6.3 Other Benefits

This study focused on using benefits of road protection in terms of reductions in snow and ice removal costs and vehicle accident rates. At the beginning of the case studies it was mentioned that there are other benefits (both market and nonmarket) that should be considered in the decision making process but have not been quantified in such a way so as to be included in an economic analysis. Some of these other benefits apply to all of the scenarios and some to only the living snowfence scenarios.

Benefits such as reductions in wear-and-tear in snow removal equipment, as well as reductions in damage to roads by this equipment are monetary benefits that have not been included in the analysis. Other benefits incurred by all snowfence designs include reduced traffic delays due to better road conditions, livestock weight gain and increased agricultural crop yields between the snowfence and road (this could actually be a cost if the vegetation needs to be mowed for aesthetics, visibility or fire control purposes).

Living snowfences provide some benefits not generated by artificial barriers. There is wildlife habitat created when the trees and shrubs provide cover and food for animals. (It should be noted this could be a disbenefit if agricultural crop damage is caused by wildlife). There is also an aesthetic component associated with living snowfences. A third possible benefit that is provided by living snowfences is the opportunity to harvest the trees at the end of the project for some type of wood product.

6.4 Comparison to Other Studies

A study done by Ron Tabler titled "Design Guidelines for the Control of Blowing and Drifting Snow," takes a different approach in estimating savings in snow and ice removal costs (Tabler 1994). The analysis in his paper calculates savings using a model based on the snowfence snow storage capabilities, snow transport, the probability of exceeding the snowfence's snow storage capacity, site conditions and snow chemistry. Using this approach Tabler derived estimates of benefit-cost ratios for snowfences ranging from 10:1 up to 50:1. These values far exceed those calculated in this study. There is an explanation for the differences in benefits calculated in this analysis and in Tabler's study.

Using unit cost estimates for mechanical snow removal Tabler calculates the savings in snow and ice removal costs assuming that all of the snow captured by the snowfence would have been deposited on the road. The model estimates the percent reduction in snow accumulating on the road as being equal to the trapping efficiency of the snowfence. For example, if the snowfence has a 90% trapping efficiency then there is a 90% reduction in snow accumulating on the road. This is an unlikely estimation of savings for two reasons. First, it does not account for snow that would accumulate on the road from direct snowfall. Second, it is unlikely that all of the snow captured by the snowfence would have accumulated on the road. As a result, Tabler's estimation of snow removal benefits are probably an overestimation of what could actually be expected. Tabler does acknowledge this and states that the model is designed to be used as a basis for determining the optimum snowfence design configuration rather than determining benefits of reduction in snow removal.

CHAPTER 7 CONCLUSIONS & RECOMMENDATIONS

Living snowfences are an effective tool for controlling blowing and drifting snow on roads, agricultural and livestock fields and around homesteads. In the case of roads, living snowfences contribute to reduced snow and ice removal costs, accident frequency, snow removal equipment wear, road damage and travel delays on roads. Snowfences also increase soil moisture on adjacent agricultural lands, reduce wind and temperature stress on livestock and help keep snowdrifts away from homes and heating costs down.

This study involved quantifying and analyzing the benefits of living snowfences designed to protect roads in order to better understand their economic impact and how they compare to other snowfence designs. The four snowfence configurations analyzed were the Wyoming board fence, three row tree and shrub, four-foot slatted snowfence and combination two-row four-foot slatted and three row tree and shrub living snowfence. They all showed positive economic returns. The combination slatted and living snowfence had the highest total net and present net benefits. The living snowfence gave the highest benefit-cost ratio and the lowest annual breakeven benefits. The Wyoming board fence had the highest SEV, and the slatted snowfence required the highest annual breakeven benefits and had the highest IRR.

Deciding which snowfence projects are best for protecting roads depends on site conditions and management objectives. The economic analysis confirms that the living snowfence is an economically viable solution, is economically competitive with other artificial snowfence alternatives, and presents the opportunity for generating other benefits (wildlife and aesthetics) not made available with artificial snowfence options. Economic analysis shows that, extending the useful life of the snowfence or reducing the amount of time it takes for the snowfence to reach full effectiveness, greatly improves its economic performance. Increasing

landholding costs and interest rate have a negative effect on the overall economic performance of snowfences, but these changes have less of an impact than changes in useful life.

In the Great Plains region, despite the recent popularity and increasing presence of living snowfences, and the longtime use of artificial barriers, there has been limited research quantifying all of the possible benefits involved with the projects. This study used the best benefit data available concerning benefits of road protection. While the economic analysis procedure is valid for any set of benefits and costs, more accurate and universal benefit estimates would improve the accuracy and applicability of the results. Therefore, it is recommended that there needs to be more research done in the following areas:

- measuring snow and ice removal costs before and after snowfence establishment under a variety of site conditions
- quantifying wildlife and aesthetic benefits of living snowfences
- studying the relationship between the length of living snowfence installed and (1) accident frequency and (2) snow and ice removal costs.

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